

EPA/DOE

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# MINE WASTE TECHNOLOGY PROGRAM

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Technology Testing for Tomorrow's Solutions



## 1998 ANNUAL REPORT

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Mine Waste Technology Program  
Interagency Agreement Management Committee  
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# VISION STATEMENT FOR THE BUTTE MINE WASTE TECHNOLOGY PROGRAM

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## THE PROBLEM

Mining activities in the United States (not counting coal) produce between 1 and 2 billion tons of mine waste annually. These activities include extraction and beneficiation of metallic ores, phosphate, uranium, and oil shale. Over 130,000 of these noncoal mines, concentrated largely in nine western states, are responsible for polluting over 3,400 miles of streams and over 440,000 acres of land. About seventy of these sites are on the National Priority List for Superfund remediation. In the 1985 Report to Congress on the subject, the total noncoal mine waste volume was estimated at 50 billion tons, with 33% being tailings, 17% dump/heap leach wastes and mine water, and 50% surface and underground wastes. Since many of the mines involve sulfide minerals, the production of acid mine drainage (AMD) is a common problem from these abandoned mine sites. The cold temperatures in the higher elevations and heavy snows frequently prevent winter site access. The combination of acidity, heavy metals, and sediment have severe detrimental environmental impacts on the delicate ecosystems in the West.

## THE PHILOSOPHY/VISION

End-of-pipe treatment technologies, while essential for short-term control of environmental impact from mining operations, are a stop-gap approach for total remediation. Efforts need to be made on improving the end-of-pipe technologies to reduce trace elements to low levels for applications in ultra-sensitive watersheds and for reliable operation in unattended, no power situations. The concept of pollution prevention, emphasizing at-source control and resource recovery, is the approach of choice for the long-term solution. Our objective in the Butte Mine Waste Technology

Program is not to assess the environmental impacts of the mining activities, but it is to develop and prove technologies that provide satisfactory short- and long-term solutions to the remedial problems facing abandoned mines and the ongoing compliance problems associated with active mines, not only in Montana but throughout the United States.

## THE APPROACH

There are priority areas for research, in the following order of importance:

### **Source Controls, Including In Situ Treatments and Predictive Techniques**

It is far more effective to attack the problem at its source than to attempt to deal with diverse and dispersed wastes, laden with wide varieties of metal contaminants. At-source control technologies, such as sulfate-reducing bacteria; biocyanide oxidation for heap leach piles; transport control/pathway interruption techniques, including infiltration controls, sealing, grouting, and plugging by ultramicrobiological systems; and AMD production prediction techniques should strive toward providing a permanent solution, which of course is the most important goal of the program.

### **Treatment Technologies**

Improvements in short-term end-of-pipe treatment options are essential for providing immediate alleviation of some of the severe environmental problems associated with mining, and particularly with abandoned ore mines. Because immediate solutions may be required, this area of research is extremely important to effective environmental protection.

### **Resource Recovery**

In the spirit of pollution prevention, much of the

mining wastes, both AMD (e.g., over 25 billion gallons of Berkeley Pit water) and the billions of tons of mining/beneficiation wastes, represent a potential resource as they contain significant quantities of heavy metals. While remediating these wastes, it may be feasible to incorporate resource recovery options to help offset remedial costs.

## THE PARTNERSHIPS

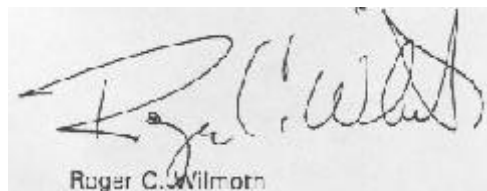
In these days of ever-tightening budgets, it is important that we leverage our limited funding with other agencies and with private industry. We are aggressively working to integrate the Butte program with the U.S. Department of Energy Resource Recovery Project to leverage both budgets. The Bureau of Land Management and Forest Service participate by providing sites for demonstrations of the technologies. It is important where these technologies have application to active mining operations to achieve cost-sharing partnerships with the mining industry to test the technologies at their sites. Within the U.S. Environmental Protection Agency, the Butte program is coordinated and teamed, where appropriate, with the Superfund Innovative Technology Evaluation (SITE) program to leverage the funding and maximize the effectiveness of both programs. Several joint projects are underway, and more are planned.

A considerable resource and willing partner is the University system (such as Montana Tech of the University of Montana, University of Montana–Missoula, Montana State University–Bozeman, and the Center for Biofilm Engineering), which can conduct the more basic type of research essential to kinetics characterization and bench-scale test more experimental, less developed concepts at minimal cost to the program, while at the same time providing environmental education that will be useful to the region and to the Nation. The Butte Mine Waste Technology Program supports cooperative projects between the educational system and the mining industry, where teams of students conduct research of mine site-specific problems, often with monetary support from the industry. The results are made available to the industry as a

whole and to the academic community.

## THE SCIENCE

The research program is peer-reviewed semiannually by the Technical Integration Committee (TIC), who technically reviews all ongoing and proposed projects. The TIC is composed of technical experts from the cooperating agencies, academia, environmental stakeholders, and industry and their consultants.



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# PROGRAM MANAGER'S EXECUTIVE SUMMARY

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The Mine Waste Technology Program (MWTP) Annual Report for Fiscal Year (FY)1998 summarizes the results and accomplishments for the various activities within the Program. After 7 years, everyone involved with the MWTP can look with pride to the Program's success. The MWTP has met its goals by providing assistance to the public and forming cooperative teams drawn from Government, industry, and private citizens. The funds expended have returned tangible results, providing tools for those faced with mine waste remediation challenges.

Technology development has proceeded successfully through the efforts of MSE Technology Applications Inc. (MSE) and its prime subcontractor Montana Tech.

MSE has developed twelve field-scale demonstrations, three demonstrations are attracting considerable attention from the stakeholders involved in the cleanup of mine wastes.

Montana Tech has developed eight bench-scale projects, five of which are also ongoing during 1997. In addition to these bench-scale projects, Montana Tech has demonstrated, also at a bench-scale, eleven water treatment technologies under the Berkeley Pit Innovative Technologies Project.

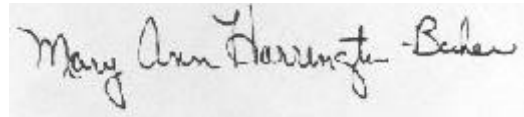
Numerous activities are associated with the development of a field-scale demonstration. Among these activities are acquiring federal and state permits, securing liability limiting access agreements, developing and adhering to health and safety operation plans, and complying with the National Environmental Policy Act and other federal and state environmental oversight statutes.

The Program has received substantial support from state and federal agencies, the mining industry, environmental organizations, and numerous associations interested in mining

and development of natural resources at state, regional, and national levels.

Montana Tech continued the post-graduate degree program with a mine waste emphasis in which 40 students have enrolled. The quality of short courses offered by Montana Tech is becoming highly recognized among the mine waste remediation community.

The MWTP recognizes its major accomplishments and looks forward to providing new and innovative technologies; meeting the challenges of mine waste remediation; and providing low cost, permanent solutions to the nation's mineral waste problems.



Mary Ann Harrington-Baker  
MSE MWTP Program Manager

# INTRODUCTION

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Mining waste generated by active and inactive mining production facilities and its impact on human health and the environment are a growing problem for Government entities, private industry, and the general public. The nation's reported volume of mine waste is immense. Presently, there are 68 sites on the Environmental Protection Agency's (EPA) National Priorities List.

Environmental impacts associated with inactive and abandoned mines (IAM) are common to mining districts around the country, as shown in Table 1.

Total estimated remediation costs for these states range from \$4 to \$45 billion.

Health effects from the predominate contaminants in mine waste range from mild irritants to proven human carcinogens, such as cadmium and arsenic. The large volume of mine wastes and consequential adverse environmental and human health effects indicates an urgency for cleanup of abandoned, inactive, and active mining facilities. The environmental future of the United States depends in part on the ability to deal effectively with mine waste problems of the past and present, and, more importantly, to prevent mine waste problems in the future.

According to a 1985 report to Congress, mining and related activities generate

anywhere from 1 to 2 billion tons of waste each year with a current total waste volume of 50 billion tons. Of this total volume, approximately 85% is attributed to copper, iron ore, uranium, and phosphate mining and related activities. Approximately one-half of the waste generated is mining waste and one-third is tailings, with the balance consisting of dump/heap leaching wastes and mine water.

The FY91 Congressional Appropriation allocated \$3.5 million to establish a pilot program in Butte, Montana, for evaluating and testing mine waste treatment technologies. The Mine Waste Technology Program (MWTP) received additional appropriations of \$3.5 million in FY91, \$3.3 million in FY94, \$5.9 million in FY95, \$2.5 million in FY96, \$7.5 million in FY97, and \$6.0 million in FY98.

The projects undertaken by this Program focus on developing and demonstrating innovative technologies at both the bench-and pilot-scale that treat wastes to reduce their volume, mobility, or toxicity. To convey the results of these demonstrations to the user community, the mining industry, and regulatory agencies, the MWTP includes provisions for extensive technology transfer and educational activities. This report summarizes progress made in FY98 by the MWTP.

**Table 1. Number and types of sites and abandoned mine lands in Western Region.**

State	Estimated Number of Sites or Land Areas	Classification and Estimated Number
Alaska	10,910 sites	mine dumps - 1,000 acres disturbed land - 27,680 acres mine openings - 500 hazardous structures - 300
Arizona	95,000 sites	polluted water - 2,002 acres mine dumps - 40,000 acres disturbed land - 96,652 acres mine openings - 80,000
California	11,500 sites	polluted water - 369,920 acres mine dumps - 171 acres mine openings - 1,685
Colorado	20,229 sites covering 26,584 acres	polluted water 830,720 mine dumps - 11,800 acres disturbed land - 13,486 acres mine openings - 20,229 hazardous structures - 1,125
Idaho	8,500 sites covering 18,465 acres	polluted water - 84,480 mine dumps - 3,048 disturbed land - 24,495 acres mine openings - 2,979 hazardous structures - 1,926
Michigan	400–500 sites	Accurate information not available.
Montana	19,751 sites covering 11,256 acres	polluted water - 715,520 acres mine dumps - 14,038 disturbed land - 20,862 acres mine openings - 4,668 hazardous structures - 1,747
Nevada	400,000 sites	Accurate information not available.
New Mexico	7,222 sites covering 13,585 acres	polluted water - 44,160 acres mine dumps - 6,335 acres disturbed land - 25,230 acres mine openings - 13,666 hazardous structures - 658
Oregon	3,750 sites	polluted water - 140,800 acres mine dumps - 180 acres disturbed land - 61,000 acres mine openings - 3,750 hazardous structures - 695
South Dakota	4,775 acres	Accurate information not available.
Texas	17,300 acres	Accurate information not available.
Utah	14,364 sites covering 12,780 acres	polluted water - 53,120 acres mine dumps - 2,369 acres disturbed land - 18,873 mine openings - 14,364 hazardous structures - 224
Wisconsin	200 acres	Accurate information not available.
Wyoming	5,000 acres	Accurate information not available.

Information was collected from the following sources and is only an estimate of the AMD problem in the West.

- Bureau of Land Management
- Bureau of Mines
- Mineral Policy Center
- National Park Service
- U.S. Department of Agriculture

- U.S. Department of the Interior
- U.S. Forest Service
- U.S. Geological Survey
- U.S. General Accounting Office
- Western Governor's Association Mine Waste Task Force Study

# PROGRAM OVERVIEW

## FISCAL YEAR 1998 PROGRAM

This MWTP annual report covers the period from October 1, 1997, through September 30, 1998. This section of the report explains the organization and operation of the MWTP.

## MISSION

The mission of the MWTP is to provide engineering solutions to national environmental issues resulting from the past practices of mining and smelting of metallic ores. In accomplishing this mission, the MWTP develops and conducts a program that emphasizes treatment technology development, testing and evaluation at bench- and pilot-scale, and an education program that emphasizes training and technology transfer. Evaluation of the treatment technologies focuses on reducing the mobility, toxicity, and volume of waste; implementability; short- and long-term effectiveness; protection of human health and the environment; community acceptance; and cost reduction.

The statement of work provided in the Interagency Agreement between the EPA and the U.S. Department of Energy (DOE) identifies six activities to be completed by the MWTP. The following descriptions identify the key features of each and the organization performing the activity.

## ACTIVITY I: ISSUES IDENTIFICATION

Montana Tech of the University of Montana (Montana Tech) is documenting mine waste technical issues and innovative treatment technologies. These issues and technologies are then screened and prioritized in volumes

related to a specific mine waste problem. Technical issues of primary interest are Mobile Toxic Constituents—Water/Acid Generation, Mobile Toxic Constituents—Air, Cyanide, Nitrate, Arsenic, Pyrite, and Selenium. Wasteforms reviewed related to these issues include point- and nonpoint-source acid drainage, abandoned mine acid drainage, stream-side tailings, impounded tailings, priority soils, and heap leach-cyanide/acid tailings.

## ACTIVITY II: GENERIC QUALITY ASSURANCE PROJECT PLAN

Montana Tech has prepared a generic quality assurance project plan that provides specific instructions on how data will be gathered, analyzed, and reported for all activities of the MWTP. Features of both the EPA and DOE quality requirements are incorporated into this plan. Project-specific quality assurance project plans are developed by MSE Technology Applications, Inc. (MSE). MSE provides oversight for all quality assurance activities.

## ACTIVITY III: PILOT-SCALE DEMONSTRATIONS

MSE began eight field-scale demonstrations during FY98. The demonstration topics were chosen after a thorough investigation of the associated technical issue was performed, the specific waste form to be tested was identified, two levels of peer review were conducted, and sound engineering and cost determination of the demonstration were formulated.

#### **ACTIVITY IV: BENCH-SCALE EXPERIMENTS**

Montana Tech successfully completed one bench-scale projects during FY97—the Sludge Stabilization Project and the Photoassisted Electron Transfer Reactions Project. In addition to the completed projects, Montana Tech conducted research on five innovative technologies that show promise for cost effective remediation of mine wastes. One major criteria for these projects was the potential for scaling to field-scale demonstrations.

The Berkeley Pit Innovative Technologies Project successfully completed three bench-scale demonstrations of treatment technologies associated with defining alternative remediation strategies for EPA's future cleanup objectives for the waters contained within the Berkeley Pit. The Berkeley Pit is an inactive, open-pit copper mine that has been filling with acidic water since pump dewatering of adjacent underground mines ceased in 1982.

#### **ACTIVITY V: TECHNOLOGY TRANSFER**

MSE is responsible for preparing and distributing reports for the MWTP. These include routine weekly, monthly, quarterly, and annual reports; technical progress reports; and final reports for all MWTP activities. MSE also publicizes information developed under the MWTP in local, regional, and national publications. Other means of information transfer include public meetings, workshops, and symposiums.

#### **ACTIVITY VI: EDUCATIONAL PROGRAMS**

Montana Tech has developed a post-graduate degree program with a mine waste emphasis. The program contains elements of geophysical, hydrogeological, environmental, geochemical, mining and mineral processing, extractive metallurgical, and biological engineering.

# ORGANIZATIONAL STRUCTURE

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## **MANAGEMENT ROLES AND RESPONSIBILITIES**

Management of the MWTP is specified in the Interagency Agreement. The roles and responsibilities of each organization represented are described below. The organization chart for the MWTP is presented in Figure 1.

## **ENVIRONMENTAL PROTECTION AGENCY**

EPA's National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio, is responsible to EPA's Office of Research and Development for management oversight of project budget, technical direction, schedule, and scope.

## **DEPARTMENT OF ENERGY**

The Director of the DOE Office of Science and Technology, Office of Environmental Restoration and Waste Management, is the principal DOE representative on the Interagency Agreement Management Committee and provides program review and approval for the MWTP. MWTP project management is provided by the Federal Energy Technology Center (FETC), which has line responsibility for applying all applicable DOE regulations to the MWTP. MSE is responsible to FETC for management oversight concerning environmental, safety, and health requirements; regulatory actions; and operational conduct of MWTP projects at the MSE Testing Facility in Butte, Montana.

## **MSE TECHNOLOGY APPLICATIONS, INC.**

MSE, under contract with DOE, is the principal performing contractor for the MWTP. The MWTP Program Manager is the point of contact for all mine waste activities. The Program Manager is responsible for Program management and coordination, Program status reporting, funds distribution, and communications.

An MSE Project Engineer has been assigned to each of the MWTP projects and is responsible to the MWTP Program Manager for overall project direction, control, and coordination. Each Project Engineer is responsible for implementing the project within the approved scope, schedule, and cost. MSE also provides all staff necessary for completing Activities III and V and oversight of Activities II, III, IV, and VI.

## **MONTANA TECH OF THE UNIVERSITY OF MONTANA**

As a subcontractor to MSE, Montana Tech is responsible to the MWTP Program Manager for all work performed under Activities I, II, IV, and VI. The responsibility for overall project direction, control, and coordination of the work to be completed by Montana Tech is assigned to the MWTP Montana Tech Project Manager.

## TECHNICAL INTEGRATION COMMITTEE

The Technical Integration Committee is a nine-member committee established to review progress in meeting the goals of the MWTP and to alert the Interagency Agreement Management Committee to pertinent technical

concerns. The committee provides information on the needs and requirements of the entire mining waste technology user community and assists with evaluation of technology demonstrations as well as technology transfer. This committee is comprised of representatives from both the public and private sectors.

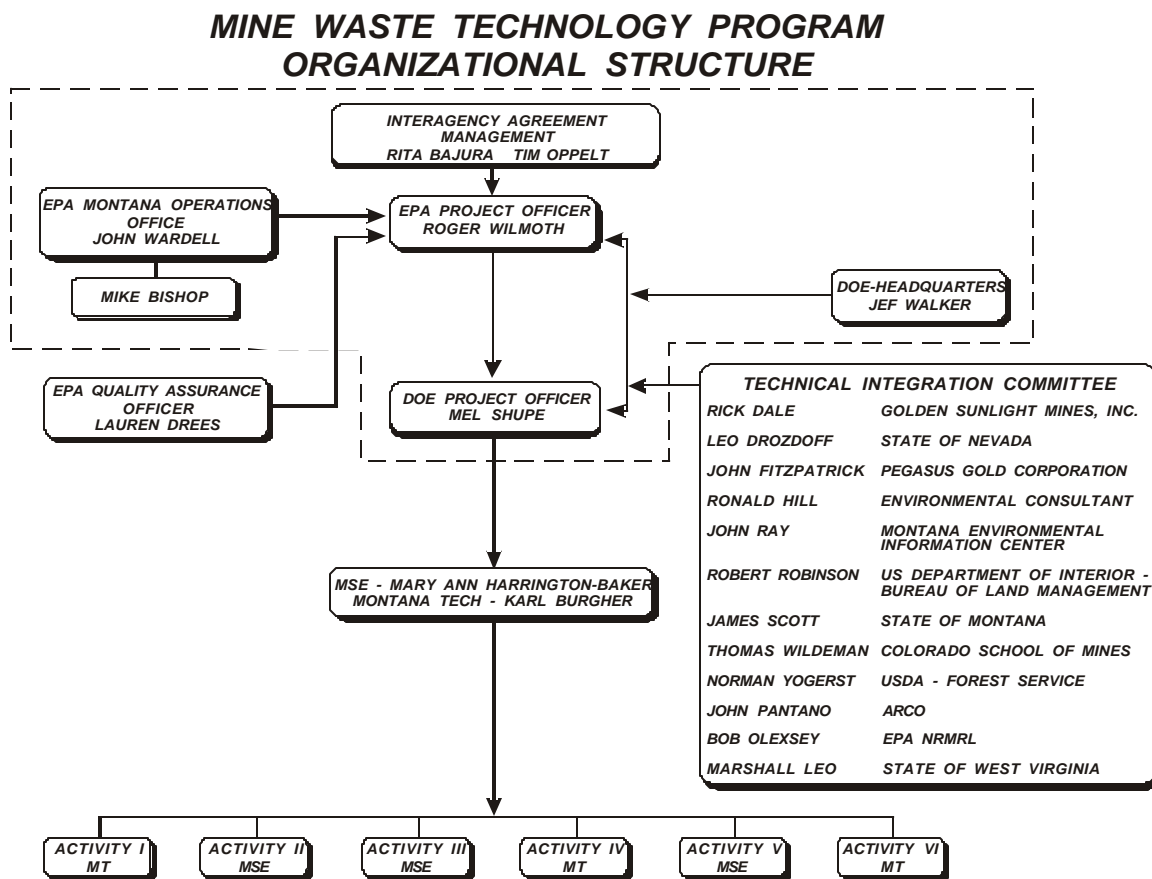


Figure 1. MWTP organizational chart.

# ACTIVITIES

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## **DESCRIPTIONS, ACCOMPLISHMENTS, AND FUTURE DIRECTION**

This section describes Activities I through VI of the MWTP and includes project descriptions, major project accomplishments during FY97, and future project direction.

### **ACTIVITY I OVERVIEW**

This activity focuses on documenting mine waste technical issues and identifying innovative treatment technologies. Issues and technologies are screened and prioritized in volumes related to a specific mine waste problem/market.

Following completion of a volume, appendices are prepared. Each appendix links a candidate technology with a specific site where such a technology might be applied. The technology/site combinations are then screened and ranked.

### **Technical Issue Status**

The status of the volumes approved for development includes:

- Volume 1, Mobile Toxic Constituents—Water and Acid Generation, complete.
- Volume 2, Mobile Toxic Constituents—Air, complete.
- Volume 3, Cyanide, complete.
- Volume 4, Nitrate, complete.
- Volume 5, Arsenic, complete.
- Volumes 1-5 Summary Report, complete.
- Volume 6, Pyrite, complete.
- Volume 7, Selenium, in progress.

- Volume 8, Thallium, in progress.
- Volume 9, Pit Lakes, in progress.

The status of the appendices for approved projects includes:

- Volume 1, Appendix A (Remote Mine Site), complete.
- Volume 1, Appendix B (Grouting), complete.
- Volume 1, Appendix C (Sulfate-Reducing Bacteria), complete.
- Volume 3, Appendix A (Biocyanide), complete.
- Volume 4, Appendix A (Nitrate), complete.

### **ACTIVITY II OVERVIEW**

The objective of this activity is to provide support to individual MWTP projects by ensuring all data generated is legally and technically defensible and that it supports the achievement of individual project objectives. The primary means of carrying out this activity is the quality assurance project plan, which is written for each project. This plan specifies the quality requirements the data must meet, clearly states the project objectives, describes all sampling and measurement activities, and contains standard operating procedures, when applicable. Other functions of this activity include reviewing technical systems, validating data, implementing corrective action, and reporting to project management.

Activity II, Preparing a Generic Quality Assurance Project Plan, was completed during FY92 and includes continuing quality assurance activities; therefore, no detailed section for Activity II is included in this report. Specific quality assurance project plans were prepared for individual projects and are described in the appropriate sections.

## ACTIVITY III OVERVIEW

The objective of this activity is to demonstrate innovative and practical remedial technologies at selected waste sites, a key step in proving value for widespread use and commercialization. Technologies and sites are selected primarily from the prioritized lists generated in the Volumes from Activity I, or they may be a scaleup from bench-scale experiments conducted under Activity IV.

## ACTIVITY III, PROJECT 1: REMOTE MINE SITE DEMONSTRATION

### Project Overview

Acidic metal-laden water draining from remote, abandoned mines has been identified by the EPA as a significant environmental hazard to surface water in the Western United States. In Montana alone, more than 3,000 such sites have been identified, and wastes from these mines have damaged over 1,100 miles of surface water in the State.

The EPA asked MSE to develop a treatment facility at one of these sites to treat acidic metal-laden water. Due to the remote nature of these locations, this facility was required to operate for extended periods of time on water power alone, without operator assistance.

An example of a remote mine site with a point-source aqueous discharge is the Crystal Mine. Located 7 miles north of Basin, Montana, the Crystal Mine was an ideal site for this demonstration. In addition, the site had been identified by the Montana State Water Quality Bureau as a significant contributor of both acid and metal pollution to Uncle Sam Creek, Cataract Creek, and the Boulder River. This project demonstrated a method for alleviating nation-wide environmental problems associated with remote mine sites.

### Technology Description

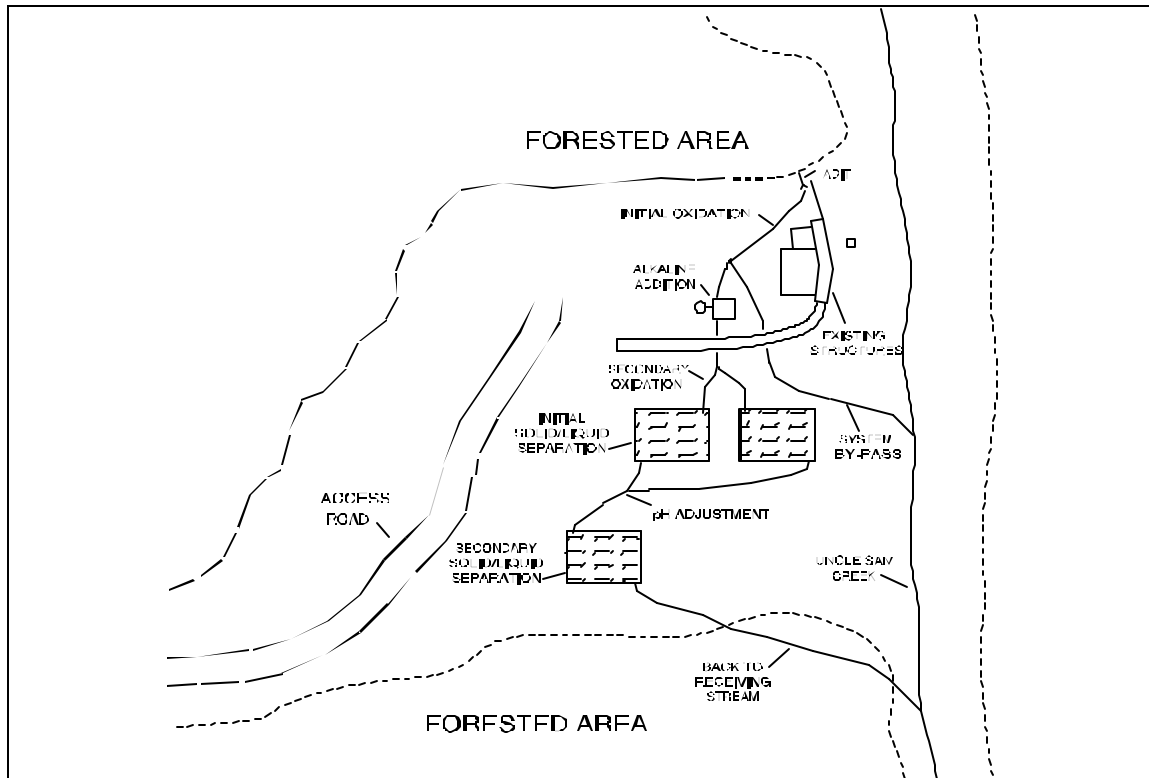
The Crystal Mine demonstration treated a flow of water ranging from 10 to 25 gallons per minute, approximately half of the total mine discharge. The process consisted of the

following six unit operations arranged as shown in Figure 2.

- Initial Oxidation—atmospheric oxygen partially oxidizes ferrous iron to the ferric form.
- Alkaline Addition—reagents form metal hydroxide solids.
- Secondary Oxidation—atmospheric oxygen oxidizes additional ferrous iron to the ferric form.
- Initial Solid/Liquid Separation—settling ponds trap precipitated solids.
- pH Adjustment—atmospheric carbon dioxide lowers the pH.
- Secondary Solid/Liquid Separation—settling pond retains additional precipitated solids.

### Status

The Remote Mine Site Demonstration Project at the Crystal Mine was conducted in the field for 2 years under all weather conditions. Construction of buildings, ponds, and associated mine site infrastructure began in late May 1994 and was completed in early August 1994. Acid mine drainage from the lower portal of the Crystal Mine began passing through the system on a full-time basis in early September 1994. Analytical data from the project showed a greater than 75% removal of toxic metals from the mine drainage. The project is closed out, and the final report has been prepared.



**Figure 2. Crystal Mine water treatment system plan view.**

## ACTIVITY III, PROJECT 2: CLAY-BASED GROUTING DEMONSTRATION

### Project Overview

Surface and groundwater inflow into underground mine workings becomes a significant environmental problem when water contacts sulfide ores, forming acid drainage. Clay-based grouting, the technology selected for this demonstration, has the ability to reduce or eliminate water inflow into mine workings by establishing an impervious clay curtain in the formation.

### Technology Description

Groundwater flow is the movement of water through fissures and cracks or intergranular spaces in the earth. With proper application, grout can inhibit or eliminate this flow.

Grouting is accomplished by injecting fine-grained slurries or solutions into underground pathways where they form a groundwater barrier. The Ukrainian clay-based grouting technology was selected for testing and evaluation because it offered a potentially long-term solution to acid mine drainage problems.

The demonstration consisted of three phases: 1) extensive geologic studies, 2) grout formulation, and 3) grout placement.

**Phase One** consisted of site characterization studies, including geophysical, geochemical, mineralogical, and hydrogeologic information directly related to the mine and its past operational procedures.

**Phase Three** consisted of grout placement. Grout was pumped into boreholes using packers to ensure grout was placed at proper intervals.

The project was finalized at the Mike Horse Mine near Lincoln, Montana. This site was selected because of its geologic characteristics. A major factor in the selection was an identified point-source inflow from Mike Horse Creek into the mine causing acid

Phase One was completed in August 1994. Phase Two was performed in the Ukraine by Spetstamponazhgeologia Enterprizes (STG) and was completed in May 1994. Hayward Baker, Inc., was awarded the subcontract to inject the clay-based grout, and they arrived at the Mike Horse Mine site during the first week of September 1994. Grout injection began September 20, 1994, and was completed November 1, 1994.

The final report was completed in May 1997.





**Figure 4. Grouting activities at the Mike Horse Mine.**



**Figure 5. Grouting activities at the Mike Horse Mine.**

## **ACTIVITY III, PROJECT 3: SULFATE-REDUCING BACTERIA DEMONSTRATION**

### **Project Overview**

Acid generation typically accompanies sulfide-related mining activities and is a widespread problem. Acid is produced chemically, through pyritic mineral oxidation, and biologically, through bacterial metabolism. This project focuses on a source-control technology that has the potential to significantly retard or prevent acid generation at affected mining sites. Biological sulfate reduction is being demonstrated at an abandoned hard-rock mine site where acid production is occurring with associated metal mobility.

### **Technology Description**

For aqueous waste, this biological process is generally limited to the reduction of dissolved sulfate to hydrogen sulfide and the concomitant oxidation of organic nutrients to bicarbonate. The particular group of bacteria chosen for this demonstration, sulfate-reducing bacteria (SRB), require a reducing environment and cannot tolerate aerobic conditions for extended periods. These bacteria require a simple organic nutrient.

This technology has the potential to reduce the contamination of aqueous waste in three ways. First, dissolved sulfate is reduced to hydrogen sulfide through metabolic action by the SRB. Next, the hydrogen sulfide reacts with dissolved metals forming insoluble metal sulfides. Finally, the bacterial metabolism of the organic substrate produces bicarbonate, increasing the pH of the solution and limiting further metal dissolution.

At the acid-generating mine site chosen for the technology demonstration, the Lilly/Orphan Boy Mine near Elliston, Montana, the aqueous waste contained in the shaft is being treated by using the mine as an in situ reactor. An organic nutrient was added to promote growth of the organisms. This technology will also act as a source control by

slowing or reversing acid production. Biological sulfate reduction is an anaerobic process that will reduce the quantity of dissolved oxygen in the mine water and increase the pH, thereby slowing or stopping acid production.

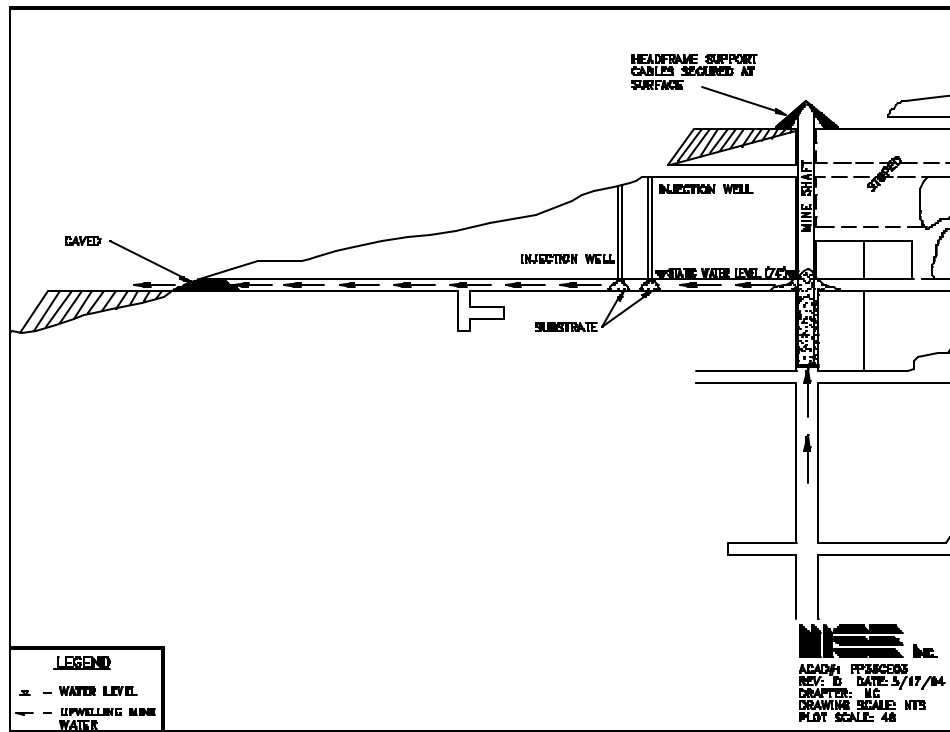
The shaft of the Lilly/Orphan Boy Mine was developed to a depth of 250 feet and is flooded to the 74-foot level. Acid mine water historically discharged from the portal associated with this level.

Pilot-scale work at the MSE Testing Facility in Butte was performed in FY94. The objective of these tests was to determine how well bacterial sulfate reduction lowers the concentration of metals in mine water at the shaft temperature (8 °C) and pH (3).

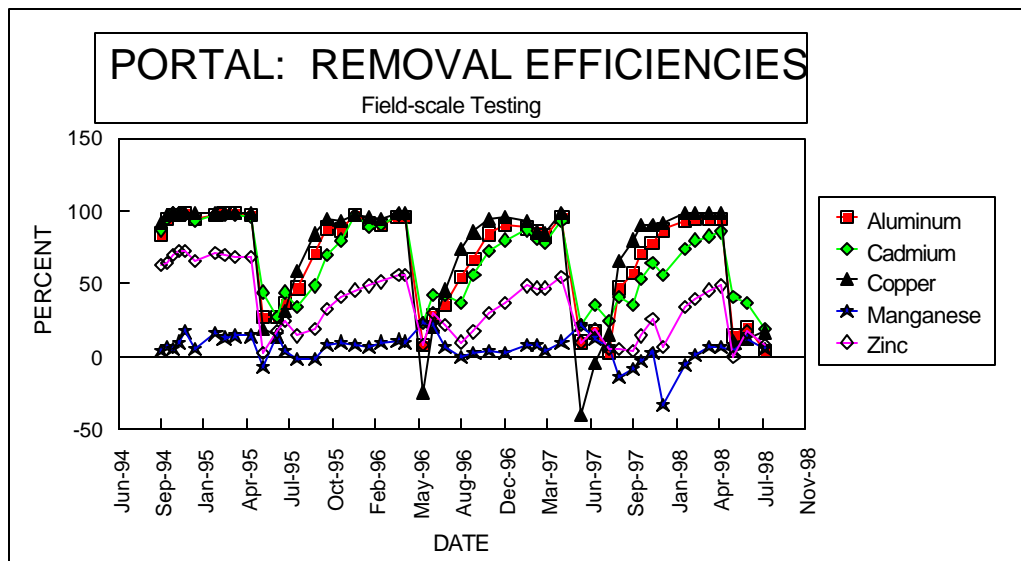
### **Status**

During FY98, the field demonstration was again monitored on a regular basis. Figure 6 presents a cross-section of the mine and technology installation.

During the past year of monitoring, the data generally demonstrated a decrease in metals concentrations (see Figure 7). An increase in metals was observed during spring runoff as occurred in prior years; however, the levels decreased when flow rates returned to normal. Monitoring of the field demonstration will continue for at least a total of 4½ years.



**Figure 6. Cross-section of the Lilly/Orphan Boy Mine and the technology installation.**



**Figure 7. Metal removal efficiency at the Lilly/Orphan Boy Mine.**

## ACTIVITY III, PROJECT 4: NITRATE REMOVAL DEMONSTRATION

### Project Overview

The presence of nitrates in water can have detrimental effects on human health and the environment. As a result, regulatory agencies have limited the allowable concentration of nitrates in effluent water.

Nitrates may be present in mine discharge water as a result of the following mining activities:

- residuals from ammonium nitrate and fuel oil (ANFO) used in blasting;
- cyanide breakdown from leaching;
- leaching of ANFO contamination from waste rock or from rock with naturally occurring nitrate; and
- residuals from fertilizer used in reclamation.

To comply with federal and state water quality standards, mining companies have typically used ion exchange or reverse osmosis to remove nitrates from discharge water. Both, however, are expensive and generate a concentrated wastestream requiring disposal.

### Technology Description

MWTP personnel undertook an extensive search to evaluate innovative technologies to resolve the nitrate problem. Of the 20 technologies screened, the following 3 showed the most promise in making nitrate removal more cost effective and environmentally responsible:

- ion exchange with nitrate-selective resin;
- biological denitrification; and
- electrochemical ion exchange (EIX).

MWTP personnel believe the best solution to the nitrate problem is some combination of the three technologies that balances capital costs with operating costs, reliability, and

minimization of wastestreams requiring disposal. Each combination has advantages and disadvantages that will be addressed during the project.

A test process train was developed that is flexible and optimizes equipment capital while acquiring value-added test data. The demonstration included the following innovative technologies as arranged in Figure 8:

- ion exchange combined with biological denitrification for destruction of the concentrated brine;
- ion exchange combined with EIX for destruction of the concentrated brine;
- biological denitrification as a stand-alone process; and
- EIX as a stand-alone process.

### Status

The Nitrate Removal Demonstration Project was conducted at the TVX Mineral Hill Mine near Gardiner, Montana, where a building to house the equipment was constructed. Figure 8 shows the equipment layout for the project. Conventional ion exchange was used to remove nitrates from the mine water and produce a concentrated brine for additional testing. Biological denitrification units and an EIX unit were used to process both mine water and concentrated nitrate brine.

The goals of the project were to remove nitrate to less than 10 milligrams per liter (mg/L) of nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ) in the effluent and to minimize the amount of waste produced. Of all the technology combinations tested, biological denitrification of concentrated nitrate brine was the most successful at meeting these goals.

Due to funding and equipment delivery delays, most of the testing was conducted during the early part of 1996 when extremely cold weather caused the mine water inlet pipe to freeze periodically. The freezing problem was finally alleviated; however, testing was delayed by the frequent shutdowns. With warmer weather, large quantities of silt appeared in the mine portal discharge. This was not anticipated and caused numerous

delays while filtering mechanisms were installed.

The nitrate ion exchange (NIX) unit was produced by Selentec, Inc. Ion exchange is a conventional, well-understood technology. As expected, the NIX unit worked well and removed nitrate from the mine water very effectively. Input levels of 20 to 40 mg/L  $\text{NO}_3\text{-N}$  were typically reduced to less than 1 mg/L. The unit also produced a concentrated brine with the predicted levels of nitrate and chloride. Frequent equipment shutdowns and muddy mine water did not affect the operation of the NIX unit.

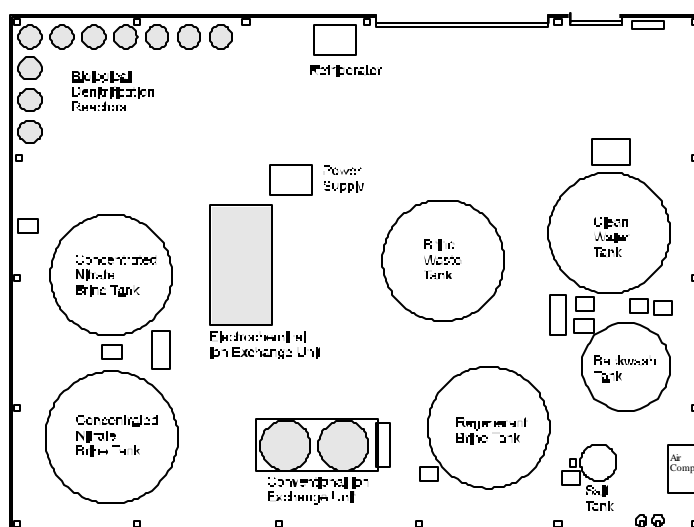
Biological denitrification was performed on both mine water and concentrated brine. As shown in Figure 9, this process worked well to eliminate nitrate in brine. Except for two process upsets (one caused by a large concentration increase), nitrate was removed to levels less than 10 mg/L  $\text{NO}_3\text{-N}$ . This removal rate met the project goals and was typically greater than 99%.

Biological denitrification of the raw mine water was less successful. A removal rate of approximately 50% was typically

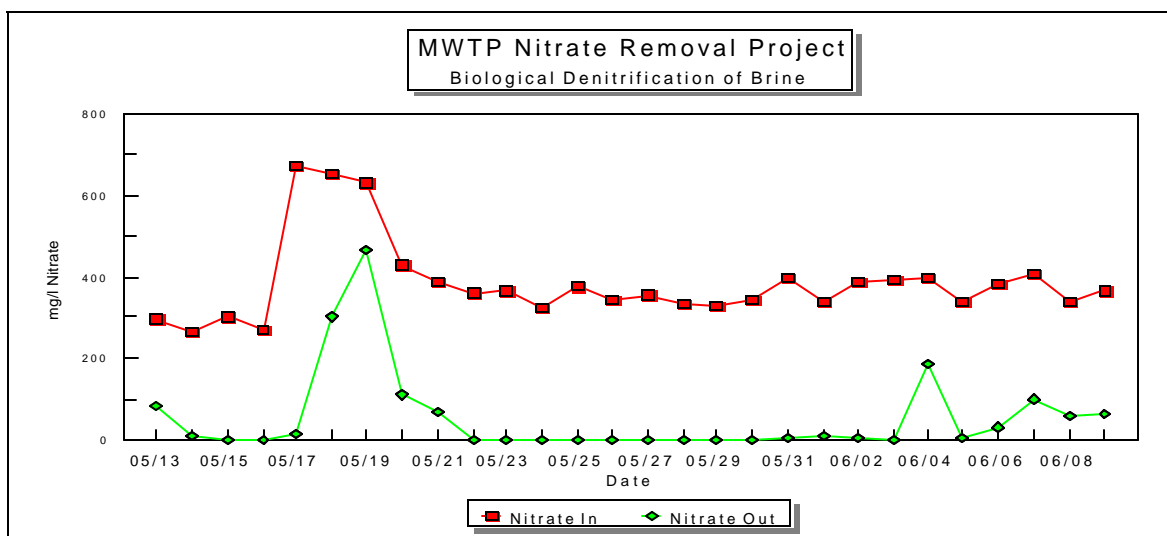
achieved. This data was taken from an operating denitrification reactor at the mine. Past data had shown that this reactor was very effective at nitrate removal. Apparently the frequent shutdowns and startups had a much more detrimental effect on these reactors.

Electrochemical ion exchange was unsuccessful at removing much nitrate from the concentrated brine because of the presence of high concentrations of a competing anion—chloride. Even though the ion exchange resin had a high affinity for nitrate ions, the 30:1 ratio of chloride ions to nitrate caused a continuous regeneration of the resin back to the chloride form and very little collection of nitrate.

Electrochemical ion exchange was able to remove nitrate from the raw mine water more effectively than from the brine. Nitrate was removed at first; however, fouling of the resin by dirty water occurred quickly, and the process was rendered ineffective after one batch. Filters were installed to alleviate the problem, but the size and nature of the particles made filtration difficult. Midway through the test sequence, the dirty resin was removed and replaced with clean resin. This worked for a while, but the resin was quickly fouled and rendered ineffective.



**Figure 8. Nitrate Removal Demonstration Project equipment layout.**



**Figure 9. Data showing nitrate removal in brine (1996).**

## ACTIVITY III, PROJECT 5: BIOCYANIDE DEMONSTRATION

### Project Overview

The primary use of cyanide in the mining industry is to extract precious metals from ores, and the use of cyanide has expanded in recent years due to increased recovery of gold using heap leach technologies. Cyanide can be an acute poison and can form strong complexes with several metals, resulting in increased mobility of those metals. As such, cyanide in mine wastewater can contribute to environmental problems.

These potential problems have led to the development of several methods to destroy cyanide and cyanide complexes in mining wastewater. Most of these processes use chemicals to oxidize the cyanide and produce nontoxic levels of carbon dioxide and nitrogen compounds. These are relatively expensive to operate.

### Technology Description

Biological destruction of cyanide compounds is a natural process that occurs in soils and dilute solutions. To take advantage of this natural destruction, a strain of bacteria was isolated by researchers at Pintail Systems, Inc. This bacteria has been tested on cyanide-contaminated mine waters and has shown

degradation rates of over 50% in 15 minutes.

The main goal of this project was to use a strain of bacteria to destroy cyanide associated with precious metal mining operations. Another project goal was to develop a reactor design that will best use the cyanide-degrading effects of the bacteria to destroy cyanide from mining wastewater.

The field demonstration portion of the project was located at the Echo Bay McCoy/Cove Mine, southwest of Battle Mountain, Nevada. The mining rate at the mine exceeds 160,000 tons of ore per day. Milling of high-grade and sulfide ores occurs simultaneously with the cyanide solution heap leaching of lower grade ores. These cyanide solutions contain 500 to 600 mg/L of weak acid dissociable (WAD) cyanide with other contaminants, such as arsenic, copper, mercury, selenium, silver, zinc, and nitrate.

### Status

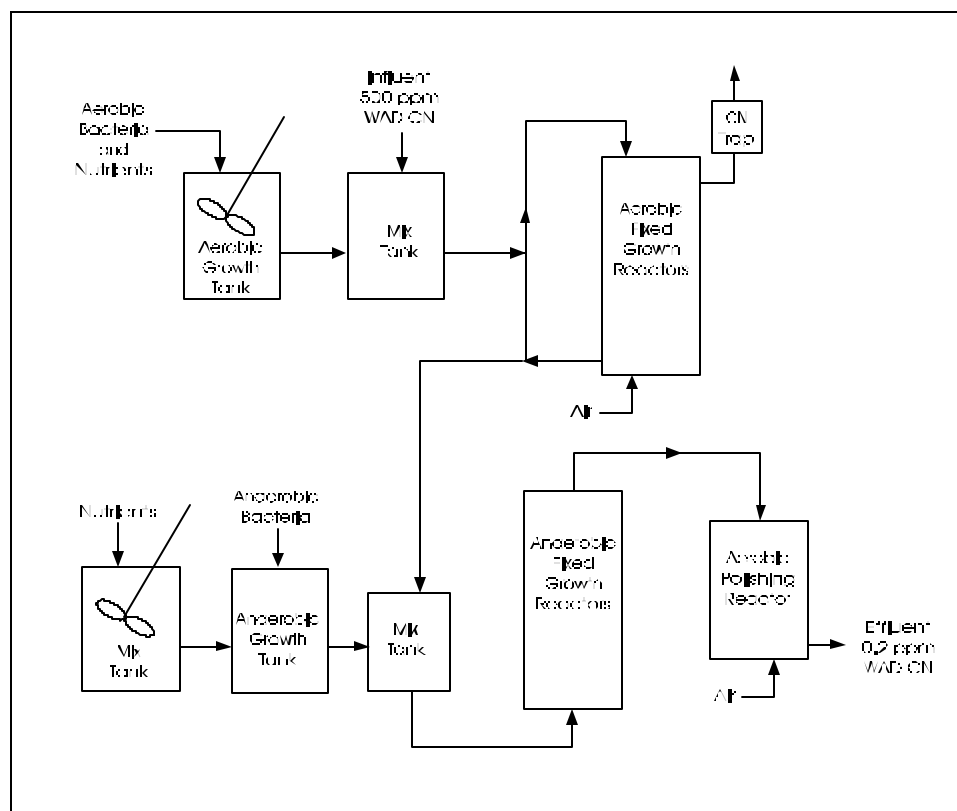
In FY96, a field-scale unit was constructed at the McCoy/Cove Mine to degrade cyanide in an existing process stream. The unit was designed to reduce the WAD cyanide concentration from 500 mg/L to less than 0.2 mg/L at flow rates of approximately 1 gallon per minute.

A bioaugmentation phase was initiated to isolate organisms and select the ones that degrade cyanide most effectively. To initiate the project, Pintail Systems, Inc., collected water samples from the mine site to isolate indigenous organisms capable of effectively degrading cyanide and performed bioaugmentation studies at their Colorado laboratory. During the bioaugmentation phase, the bacteria were subjected to increasing concentrations of cyanide to select the most capable organisms.

The bacteria selected during the bioaugmentation process were then placed on fixed growth media in bench-scale reactors. Next, actual cyanide mine water was processed through the reactors to study the kinetics of cyanide degradation. The results from these tests were then used to design the pilot-scale reactors to be used at the mine. The final process train, which includes both aerobic and anaerobic cyanide-degrading organisms, is

shown in Figure 10. The process train consists of tanks where the aerobic and anaerobic bacteria are grown in large quantities. The bacteria are then pumped to the reactors for reinoculation. The cyanide solution enters the aerobic reactor first where aerobic organisms degrade a large portion of the cyanide. The solution then moves through a series of anaerobic units for further degradation. Finally, an aerobic polishing step removes the last traces. Since cyanide is known to degrade by mechanisms other than biological, a series of control reactors was installed to run concurrently with the biological reactors.

Testing of the pilot-scale unit was performed during the summer of 1997. Cyanide and heavy metals were substantially removed from the mine process water. The pH was consistently neutralized. A preliminary scale-up cost estimate indicated substantial savings over conventional technologies. The final report was delivered to EPA in FY98.



**Figure 10. Biocyanide Demonstration Project.**

## ACTIVITY III, PROJECT 6: POLLUTANT MAGNET

## Project Overview

This project was forwarded to the MWTP by personnel from EPA's NRMRL. The concept of the pollutant magnet was to develop, produce, and test particles that have specific magnetic properties and have the ability to remove specific pollutants from a wastestream. After program personnel reviewed the project, they determined that the project be dropped from the MWTP due to its similarity with competing technologies that were more developed and had a nonmining specific use.

## **ACTIVITY III, PROJECT 7: ARSENIC OXIDATION**

### **Project Overview**

The Arsenic Oxidation Project was proposed to demonstrate and evaluate arsenic oxidation and removal technologies. The technology being demonstrated during this project was developed jointly by the Cooperative Research Center for Waste Management and Pollution Control Limited (CRC-WMPC) and the Australian Nuclear Science & Technology Organization (ANSTO) from Lucas Heights Research Laboratories in Lucas Heights, New South Wales, Australia.

Arsenic contamination in water is often a by-product of mining and the extraction of metals such as copper, gold, lead, zinc, silver, and nickel. This contamination will continue to grow as high-grade ores with low arsenic content are being depleted and the processing of sulphide ores with high arsenic content becomes increasingly common. In most cases, it is not economical to recover the arsenic contained in process streams because there is little demand worldwide for arsenic. Arsenic can be present in leachates from piles of coal fly ash, in contaminated groundwaters, in geothermal waters, and in acid drainage from pyritic heaps that result from the past practices of mining of metallic ores.

Trivalent arsenic, arsenic(III), or arsenite compounds have been reported to be more toxic than the corresponding pentavalent arsenic, arsenic(V) or arsenate forms, and much more difficult to remove from solution. Consequently, there is a need to convert

arsenic(III) to arsenic(V) to achieve effective arsenic removal from solution.

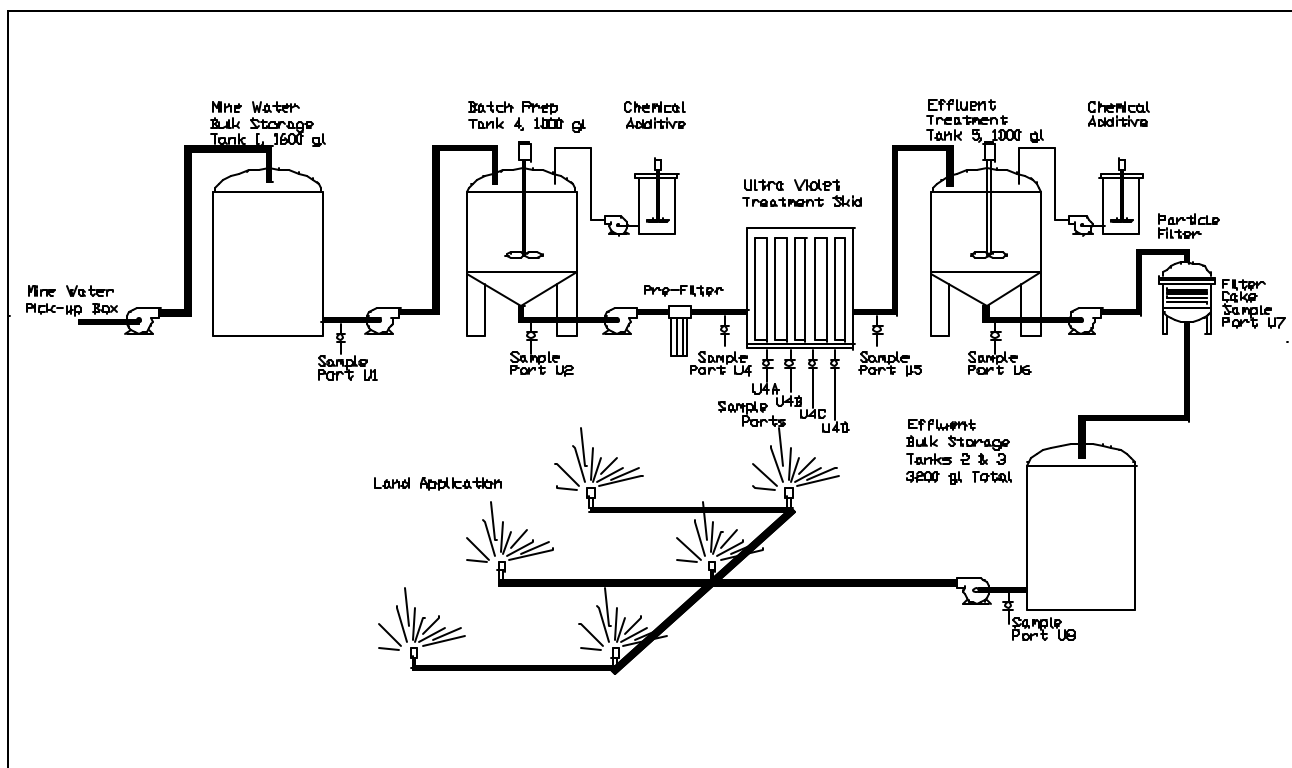
### **Technology Description**

The small-scale pilot project demonstrated a two-step process for removing arsenic from contaminated mine water. The first step and primary objective of this project was to evaluate the effectiveness of a photochemical oxidation process to convert dissolved arsenic(III) to arsenic(V) using dissolved oxygen as the oxidant. The technology provides a method for the oxidation of arsenic(III) in solution by supplying an oxidant, such as air or oxygen, and a nontoxic photo-absorber, which is capable of absorbing photons and increasing the rate of arsenic(III) oxidation to the solution. The photo-absorber used is economical and readily available. Ultraviolet oxidation using high-pressure mercury lamps and solar energy was tested. The second step of this project resulted in the removal of arsenic(V) from the solution by using an accepted EPA method, adsorption using ferric iron (see Figure 11).

## Status

The field demonstration and final report were completed. The photochemical oxidation process was very effective at oxidizing arsenite to arsenate at optimum conditions in the batch mode for both the solar tests and the photoreactor tests; however, design problems with the photoreactor unit in the continuous mode

would not allow ANSTO to achieve their claim of 90% oxidation of arsenite in solution. Channeling of the process waters in the photoreactor unit was the reason for poor oxidation of arsenite, and steps to correct the problem during the field demonstration were unsuccessful. Modifications to the baffle system are necessary to prevent further channeling.



**Figure 11. Photoreactor UV arsenic oxidation and removal, batch or continuous flow methods.**

## **ACTIVITY III, PROJECT 8: UNDERGROUND MINE SOURCE CONTROL**

### **Project Overview**

A significant environmental problem at abandoned underground mines occurs when the influx of water contacts sulfide ores and forms acid and metal-laden mine discharge. The Underground Mine Source Control technology was selected to demonstrate that select materials can be used to reduce and/or eliminate the influx of water into the underground mine system; thus, forming an impervious barrier resulting in a reduced, long-term, environmental impact caused by the abandoned mine.

### **Technology Description**

Groundwater flow is the movement of water through fractures, fissures, or intergranular spaces in the earth. With proper application, emplacement of source control materials can inhibit or eliminate this flow.

For this demonstration, a selected source control material will be injected into the fracture system that intercepts the underground mine workings. Some of the fractures are naturally occurring, others were the result of blasting used to further advance the mine workings.

By injecting a source control material, underground pathways (fractures) will be sealed, and an impervious groundwater barrier will be formed. Materials testing will be performed to determine which source control material will be selected. The material will have to be acid resistant, economical, and have rheological properties. As a result, the source control material will offer a potentially long-term solution to acidic and metal-laden water drainage problems.

The demonstration will consist of three phases: 1) extensive site characterization; 2) source control materials testing; and 3) source control material emplacement in the underground mine workings.

Phase One consisted of site characterization studies, including hydrogeological, geological, geochemical, and geophysical information directly related to the mine and its past operational procedures.

Phase Two encompasses the source control materials testing. Approximately 40 materials were tested per ASTM methods for acid resistiveness, shear strength, plasticity, compressive strength, compatibility, and viscosity. When compared to a cement-based source control material, the selected material will offer the following advantages: greater retention of plasticity; less deterioration due to the acidic conditions and during rock movement; and better rheological characteristics.

Phase Three will consist of source control material(s) emplacement. The material will be injected into boreholes at the specified intervals using packers to ensure the material is placed into the proper fracture system.

### **Status**

The project site selected for the demonstration project is the Miller Mine located near Townsend, Montana. This site was selected because the underground workings were accessible, it had a point-source discharge into the underground workings, the slightly acidic inflow is laden with heavy metals, and the inflow could be potentially controlled using the source control technology.

Phase One will be completed in March 1999, and the information will be used in the definitive design phase of the project. Phase Two was performed at MSE and will be finalized during March 1999. Phase Three, the field emplacement, is scheduled to be initiated during August 1999.

## ACTIVITY III, PROJECT 9: ARSENIC REMOVAL

### Project Overview

The purpose of the Arsenic Removal Demonstration Project was to demonstrate alternative treatment technologies capable of removing arsenic from mineral industry effluents to below 50 ppb. Several technologies with potential application to treat arsenic problems were presented in the MWTP Activity I, Volume 5, *Issues Identification and Technology Prioritization Report—Arsenic*. Each technology was screened and prioritized on the basis of its potential to reduce arsenic levels in the mineral industry. Two innovative technologies were selected, Mineral-Like Precipitation and Alumina Adsorption with Microfiltration. The Ferrihydrite Adsorption technology, EPA's Best Demonstrated Available Technology (BDAT) for removal of arsenic, was used for comparative purposes.

Potential waste streams to use for the demonstration were identified and prioritized in the MWTP Activity I, Volume 5, Appendix A, *Issues Identification and Prioritization for Arsenic*. Three different waters were treated: ASARCO's East Helena lead smelter scrubber blowdown water [containing >3 grams per liter (g/L) arsenic and many other associated metals]; ASARCO's East Helena water treatment thickener overflow water [containing -6 parts per million (ppm) arsenic]; and TVX Mineral Hill Mine 1,300-foot portal groundwater (containing -500 ppb arsenic). The Arsenic Removal Demonstration Project field activities were completed. The project report is scheduled to be sent to the EPA National Risk Management Research Laboratory in December 1998.

### Technology Description

#### **Mineral-Like Precipitation**

The concept of this process is to strip arsenic from solutions in a manner to produce mineral-like precipitated salts that are stable for long-term storage in outdoor pond-type environments. This process (see Figure 12) was developed by Dr. Larry Twidwell of

Montana Tech of the University of Montana and may be accomplished by precipitation from solutions containing arsenate and phosphate. The concept was to substitute arsenate into an apatite structure, thereby, forming a solid solution compound that would be thermodynamically stable in an outdoor storage environment.

#### **Alumina Adsorption**

Alumina adsorption technology uses aluminum oxide to adsorb arsenic onto its surface. The process (see Figure 13) is completed over a specific pH range. After absorption, reagents are added to the alumina to desorb the arsenic into a concentrated brine. The concentrated arsenic brine solution is then treated using an iron adsorption technology to remove and stabilize the arsenic. The activated alumina in the process is recycled following the desorption process by treatment with sodium hydroxide.

#### **Ferrihydrite Adsorption**

Ferrihydrite technology is an industrial technique commonly used for dissolved heavy metal removal. For ferrihydrite adsorption to occur, the ferric iron ( $\text{Fe}^{+3}$ ) must be present in the water to be treated. Dissolved arsenic is removed by a lime neutralization process in the presence of the ferric iron, which results in the formation of arsenic-bearing hydrous ferric oxide (ferrihydrite).

### Status

All three addressed technologies (iron coprecipitation, alumina adsorption, and mineral-like precipitation) showed favorable results for arsenic removal using groundwater; however, using industrial process wastewater, only two of the technologies (mineral-like precipitation and ferrihydrite adsorption) were capable of removing arsenic to below discharge standards. The complex chemistry of the industrial wastewater had a profound effect on arsenic removal using alumina adsorption.

#### **Mineral-Like Precipitation**

Mineral-like precipitation removed significantly more of the arsenic in each of the demonstrations than the stated goal of the project [i.e., to lower the arsenic content in the

effluent water to less than the drinking water standard for arsenic (<50 ppb)]. In fact, the final arsenic content in the effluent waters was in most cases <10 ppb.

### ***Alumina Adsorption***

Alumina adsorption technology was very successful in removing arsenic when treating TVX's Mineral Hill Mine 1,300-foot portal groundwater (containing ~500 ppb arsenic to 21 ppb arsenic). Treating ASARCO's lead smelter thickener overflow water (containing ~6.0 ppm arsenic and many other associated metals) with this technology removed the arsenic to 200 ppb. Other species (e.g., sulfate) competed and interfered with available alumina adsorption sites.

### ***Ferrihydrite Adsorption***

Ferrihydrite adsorption technology was successful in treating both the demonstration waters. Using an iron/arsenic mole ratio of 8 produced adequate results; however, the arsenic drinking water discharge standards of <50 ppb were never achieved treating the thickener overflow water with a mole ratio of 8. Increasing the iron to arsenic mole ratio to 10 when treating both the thickener overflow water and the Mineral Hill Mine 1,300-foot portal groundwater lowered arsenic concentrations to less than discharge standards.

### ***Economic Evaluation***

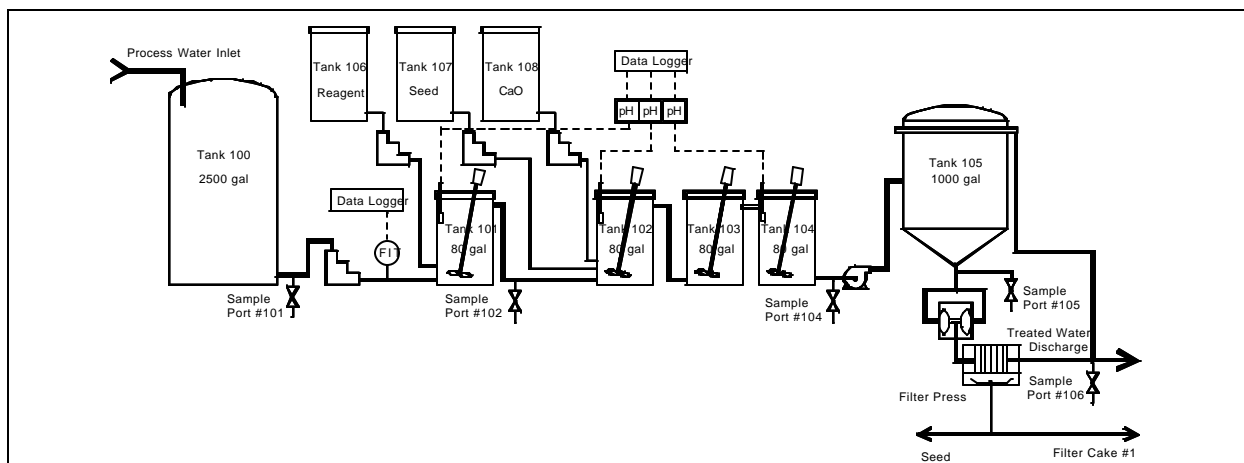
One objective of this study was to perform a first-order cost estimate for the developed treatment flowsheets. Therefore, a *first-order* cost estimate was performed. The cost estimate presented here is not a detailed engineering cost analysis. It is a first-order cost estimate that should be within  $\pm 30\%$ . Parameters for the economic evaluation for the selected technologies were to treat a groundwater with 500 ppb arsenic to <50 ppb arsenic at a rate of 300 gpm.

*Mineral-like precipitation* would require capital costs of \$250,000  $\pm$  \$75,000 and operation and maintenance (O&M) per year of \$41,080. The O&M costs per 1,000 gallons treated are \$0.30  $\pm$  \$0.09.

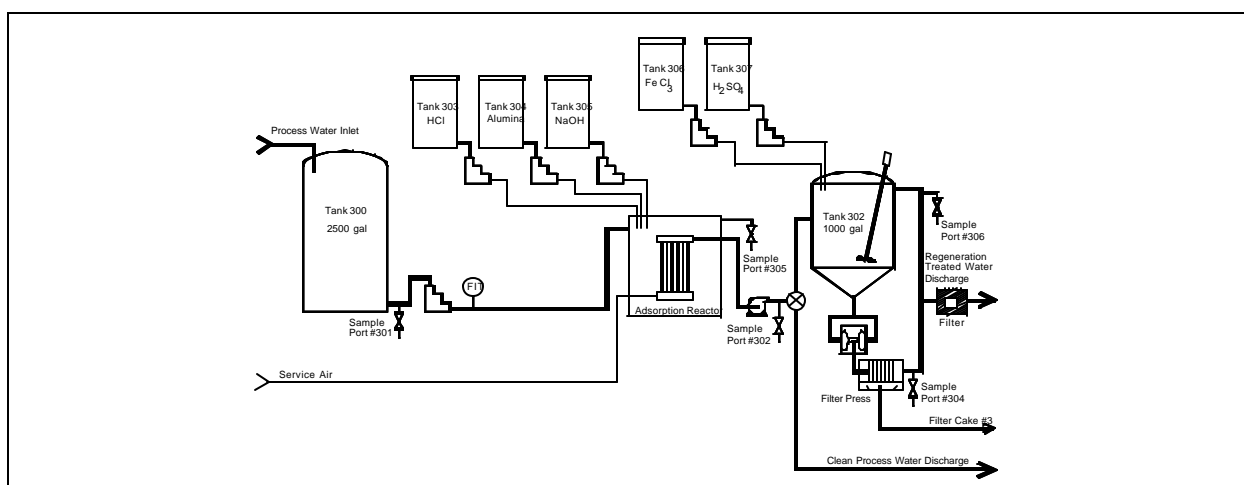
*Alumina adsorption with microfiltration* would require capital costs of \$396,000  $\pm$  \$118,800 and O&M per year of \$130,700. The O&M

costs per 1,000 gallons treated are \$0.70  $\pm$  \$0.30.

*Ferrihydrite adsorption* would require capital costs of \$250,000  $\pm$  \$75,000 and O&M per year of \$78,904. The O&M costs per 1,000 gallons treated are \$0.55  $\pm$  \$0.16.



**Figure 12. Mineral-Like Precipitation Process Flow Diagram.**



**Figure 13. Alumina Adsorption Process Flow Diagram.**

## **ACTIVITY III, PROJECT 10: SURFACE WASTE PILES—SOURCE CONTROL**

### **Project Overview**

Historically, surface waste piles from mining operations were usually placed in drainage basins in front of the haulage tunnel. Surface water in the drainage, discharge from the mine, and precipitation usually contacted the waste pile. The water came in contact with the sulfide ore in the pile and infiltrated through the pile, where acid formed and the water became metal-laden. This water percolated from the toe of the pile and flowed into the closest surface water. By injecting source control materials strategically in the surface waste pile, there will be a decrease in waters infiltrating through the pile, thereby, decreasing the environmental impact caused by the pile. This technology will be applied in situ, meaning that the pile will be stabilized in place and not excavated and moved to another location for stabilization.

### **Technology Description**

Surface waste piles from historical mining activity, in many cases, consist of broken, low-grade, sulfide ores. When water and oxygen contact the sulfide ores, acid is formed, resulting in increased levels of dissolved metals in the water associated with the pile. The source of the water infiltrating the pile is usually from direct precipitation onto the pile and/or from surface water (i.e., discharge water from a mine adit, stream flow, or in some instances ponded stream/discharge water). Finally, when the water discharges from the surface waste pile, it is acidic and metal-laden, thereby, causing a significant environmental problem.

Usually in such situations, the surface waste pile is excavated and placed in a designed repository. However, this can be expensive, and in some instances, excavation of the pile or construction of a repository is not feasible. In certain instances, in situ placement of a source control material into the pile is the optimal solution. The source control material is strategically placed into the surface waste pile such that the infiltration of water through

the pile is eliminated or reduced, resulting in a reduction of acidic, metal-laden water.

The demonstration consists of three phases initially: 1) site characterization; 2) source control materials testing; and 3) field emplacement.

Phase One consists of site characterization, which includes geochemical, geological, hydrogeological, and mineralogical studies that will provide information directly related to the surface waste pile, the mine, the regional water system, and past operational procedures.

Phase Two encompasses source control materials testing. Selected source control materials are being tested to determine if the material is acid resistant, is affected by wet/dry or freeze/thaw cycling, and if the material will be impervious once it has been emplaced into the surface waste pile materials. The physical characteristics of the surface waste pile material will also be defined in a bench-scale laboratory setting.

### **Status**

The project site for this demonstration is the Peerless Mining Property located south of Rimini, Montana. The site was selected because of its size, hydraulic characteristics, and its water quality. A major factor in the selection of the site was that it had an acidic, metal-laden, point-source discharge flowing from the toe of the surface waste pile and the upgradient water sources were of better quality and near neutral pH.

Phase One and Phase Two are scheduled to be finalized by March 26, 1999. Phase Three, involving field emplacement, is scheduled to be initiated June 1999.

## **ACTIVITY III, PROJECT 11: CYANIDE HEAP BIOLOGICAL DETOXIFICATION DEMONSTRATION**

### **Project Overview**

Following commercial gold production, mine operators are required to reclaim their properties, including eliminating cyanide from heap leach facilities. Many heap operators simply perform extended and continuous rinses of their heaps using mine process waters. Other heap operators use commercially available chemical reagents to destroy cyanide such as hydrogen peroxide or calcium hypochlorite. Recent advances in biological technologies have allowed operators to inoculate their heaps with bacterial cultures that accelerate and enhance the cyanide degradation processes.

### **Technology Description**

The basic process for bio-detoxification of cyanide heaps has already been identified, demonstrated, and proven to be commercially applicable and effective. However, numerous questions remain about the final efficiency, total capital and operating costs, applicability to multiple ore types, time required to completion, and the effects of the biological treatment on related discharge parameters such as pH, sulfates, nitrates, and entire suites of metals, including recoverable *spike* concentrations of gold.

The original technology demonstration plan for this project was to perform the tests on a full-scale, medium size mine heap. Numerous potential heaps were identified but subsequently ruled out for a myriad of reasons, including ongoing mine operations, heap size (too big and too small), heap impermeability, cyanide levels, previous bacterial inoculations, etc. In the course of heap search activities, a technology provider suggested using large-scale vertical test columns provided by McClelland Laboratories, Inc., in Sparks, Nevada. The results from such large column tests have been demonstrated to compare very well with respect to predicting cyanide neutralization

rinse data, dissolved gold recoveries, metals (copper and silver) stabilization, and final effluent water quality from full-scale heaps.

The test columns being used are approximately 4 feet in inside diameter and approximately 22 feet high. The columns are constructed of high density polyethylene to avoid evaporation/seepage from the column and any potential chemical reactions with concrete columns and/or the epoxy sealants placed thereon. The columns were loaded with approximately 12 tons of ore from a Nevada heap scheduled for decommissioning in 2004.

For experimental controls, two identical control columns have been run simultaneously. The control columns are rinsed with process waters from the same mine operation and a chemical cyanide destruction reagent (i.e., peroxide) respectively.

### **Status**

MSE has brought together four companies who lead the nation in providing commercial bio-cyanide destruction. These four companies are demonstrating their bacteriological capabilities side-by-side, under controlled operating conditions.

The six columns (four commercial and two controls) were assembled during November 1998 (see Figure 14) and rinsed for two weeks using mine process water to equilibrate. On December 3, 1998, the four biological columns were simultaneously inoculated with bacteria. The peroxide control column was simultaneously initiated. The water control column continues unchanged.

The columns are anticipated to run for approximately 90 days. Reports will be available by mid 1999.



**Figure 14. MSE safety personnel supervising assembly of the six test columns in Sparks, Nevada.**

## **ACTIVITY III, PROJECT 12: SULFATE-REDUCING BACTERIA REACTIVE WALL DEMONSTRATION**

### **Project Overview**

Thousands of abandoned mine sites in the Western United States impact the environment

by discharging acid mine drainage (AMD) to surface water or groundwater. AMD is formed when sulfide-bearing minerals, particularly pyrite, exposed by mining activities to oxygen and water, engage in a chemical reaction that results in an increased acidity of the water (lowered pH), and increased concentration of dissolved metals and sulfate.

At many abandoned mine sites in the West, conventional treatment strategies for AMD (e.g., lime neutralization) are not feasible because of the remoteness of the mine locations, insomuch as a lack of a power source and limited site accessibility in winter. Sulphate-reducing bacteria (SRB) are capable of reducing the sulfate to sulfide, decreasing the load of dissolved metals in the effluent by precipitating metals as sulfides, and increasing the pH of the effluent. To demonstrate the feasibility of using SRB passive technology for mitigation of AMD emanating from the toe of a waste rock pile, three bioreactors were built at the abandoned Calliope Mine site located near Butte, Montana.

### **Technology Description**

The abandoned Calliope Mine site includes a collapsed adit discharging water into a large waste rock pile. This relatively good quality water percolates through the mine waste and reappears on the surface (at the toe of the pile) enriched in metals with an average pH of 2.6. This AMD mixes with good quality surface water and accumulates in a pond (lower pond). As a result, the pH of water in the lower pond ranges from 3 to 5.5 depending on the surface water and AMD mixing ratio, which varies seasonally. This low pH water in the lower pond is the target water for the SRB technology demonstration.

Three SRB bioreactors constructed at the Calliope abandoned mine site in the fall of 1998 are approximately 70 feet long, 14 feet wide, and 6 feet high. They are placed in parallel (see Figure 15) downstream from the lower pond, allowing the AMD to be piped to and treated by the respective reactors using gravity flow.

The bioreactors were designed to evaluate the SRB technology applied under different environmental conditions. Each bioreactor was designed with mechanisms to enable simulation of seasonal dry and wet climatic conditions. This goal was achieved by constructing intake sumps where hydraulic heads could be controlled through the system of valves and overflow piping. In addition, a water gate was constructed upstream from the lower pond to curb the volume of surface water flowing into the lower pond, thereby, enabling a crude control of the water quality in the lower pond.

Two bioreactors were placed in trenches, and one was constructed above the ground, using a 12-foot-wide metal half-culvert, to investigate impact of seasonal freezing and thawing on SRB activity. Two bioreactors contain a passive pretreatment section to increase pH of effluent before the AMD enters the reactive chamber to evaluate the effect of inducing an optimal pH and  $E_H$  into AMD on the efficiency of the SRB.

Each reactor was filled with a combination of organic carbon, crushed limestone, and cobbles placed in discrete chambers (see Figures 15 and 16). Each of these media is expected to play a certain role in the treatment train. 1) Organic carbon is bacterial food supply and, because it was provided in the form of cow manure, also the SRB source. 2) For the pretreatment section, a chamber with cow manure was included to lower the  $E_H$  of AMD. 3) Crushed limestone provides buffering capacity to increase the pH of AMD in the pretreatment section. 4) Cobbles placed in the *reactive*, primary treatment section of the bioreactor constitute stable substrate for bacterial growth.

Chambers filled with organic carbon or limestone are each 5 feet long, whereas, chambers filled with cobbles are 50 feet long. Such dimensions were selected based on the literature review and information acquired through the bench-scale test that was commenced in the MSE laboratory in March 1998 and is scheduled to be completed in February 1999. Preliminary results of the bench-scale test, at the time of the bioreactor's design, indicated that the

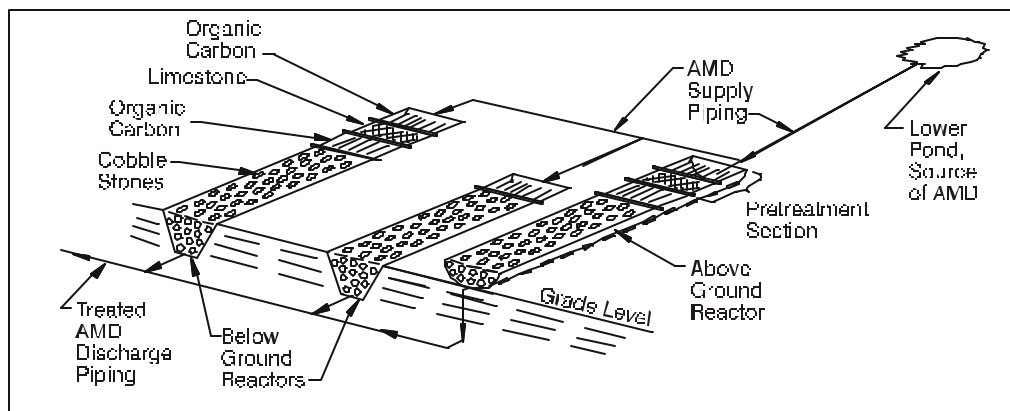
required residence time in the reactor should range from 3 to 5 days. The bioreactors were sized to secure such a residence time for the flow rate of one gallon per minute through each reactor. Nevertheless, the flow and hydraulic head control systems placed in the bioreactors ensure a much wider range of the residence time.

One of the main challenges was to design the organic carbon chambers so that they foster permeation of the AMD through the entire cross-sectional area (without *channeling*), and that the organic substrate does not settle. The solution to this challenging requirement was threefold. 1) Cow manure was mixed (80% to 20% by volume) with cut straw to provide *secondary* porosity to the mix and make the substrate less compacted. 2) The mix of cow manure and straw was installed in the cellular containment system assembled of 10 lifts of Terracell™ (see geogrid in Figure 16) that would limit settling (if occurred) of the organic matter to each individual cell. 3) The Terracell™ lifts were positioned at 60° off the horizontal plane to facilitate packing it with the manure mix and to promote migration of AMD along a wavy-shaped flowline (patent in progress).

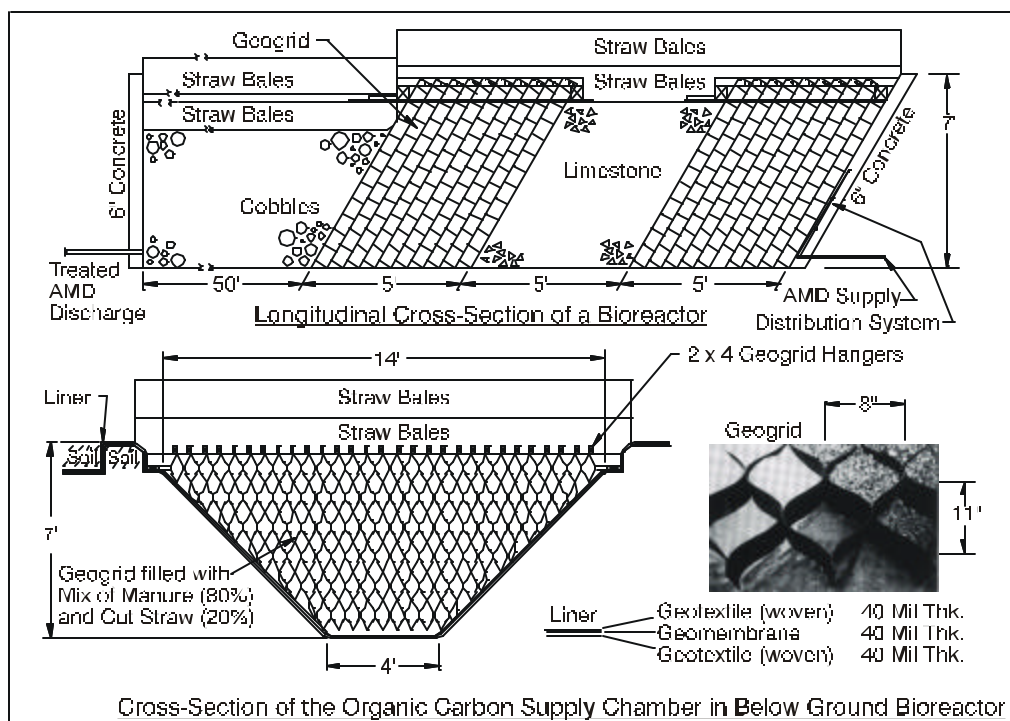
## Status

In FY98, the construction of the bioreactors was 80% completed. Installation of the bioreactor performance monitoring

instruments is scheduled for November 1998. The field testing phase, i.e., operation of the bioreactors, should be commenced by the end of November 1998.



**Figure 15. Layout of bioreactors.**



**Figure 16. Bioreactor's design.**

## **ACTIVITY III, PROJECT 13: HYDROSTATIC BULKHEAD WITH SULFATE-REDUCING BACTERIA**

required to ensure the integrity of a bulkhead installation.

### **Project Overview**

The technology addressed in this project is designed to reduce or eliminate acid drainage from underground mine workings. The demonstration is intended to illustrate the feasibility of using an innovative source control technology in a way that provides increased stability, structural applicability and continuity, and economical comparability to the conventional methods of acid drainage treatment used by the mining and waste industries. The technology used for this demonstration will be stable in the environment.

### **Technology Description**

The technology selected for this demonstration is a combination hydrostatic bulkhead constructed of concrete and rebar, with a colony of sulfate-reducing bacteria (SRB) placed behind the bulkhead. The acid drainage in the mine will be treated by raising the pH of the contained water behind the bulkhead causing metals to be removed. The metals removal processes that can occur include adsorption and complexation of metals by organic substrates, biological sulfate reduction followed by precipitation of metals as sulfides, precipitation of ferric and manganese oxides, adsorption, adsorption of metals by ferric and manganese hydroxides, and filtration of suspended and colloidal materials. Biological sulfate reduction, however, should be the predominant metal removal mechanism.

### **Status**

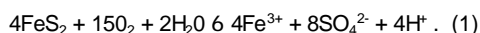
The search for a suitable site has resumed after abandonment of the project at the Sure Thing Mine south of Elliston, Montana. The native rock in the tunnel at the Sure Thing proved to be unsuitable for installing a bulkhead. Hard and competent rocks are

## ACTIVITY III, PROJECT 14: BIOLOGICAL COVER DEMONSTRATION

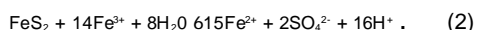
### Project Overview

Acidic, metal-laden water draining from abandoned mines is a significant environmental impact to surface waterways throughout the nation and the world. Specifically, the State of Montana has identified more than 20,000 abandoned mine sites, on both public and private lands, resulting in more than 1,300 miles of streams experiencing pollution problems.

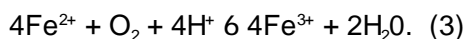
This problem arises from waste rock containing sulfide minerals and lacking acid-consuming carbonate minerals. Sulfide minerals, such as pyrite ( $\text{FeS}_2$ ) are oxidized to form sulfate when water-containing oxygen infiltrates tailings. This process can be described by the following reaction:



The activity of bacteria, such as *Thiobacillus ferrooxidans*, which are capable of oxidizing inorganic sulfur compounds, greatly accelerates this reaction (Brierley, 1978). The ferric iron ( $\text{Fe}^{3+}$ ) produced in the above reaction also contributes to pyrite oxidation:



*T. ferrooxidans* is also capable of oxidizing ferrous iron ( $\text{Fe}^{2+}$ ) produced in the above reaction:



Thus, the ferric iron is regenerated and capable of oxidizing more pyrite. The key to breaking this cycle is preventing the initial oxidation of pyrite. Bound with iron, the sulfur in pyrite is unable to participate in the microbially catalyzed reactions that cause acid generation. Prevention of oxygen infiltration into tailings then is necessary to prevent oxidation of pyrite and subsequent acid generation. An innovative method to prevent oxygen transport into tailings is the construction and maintenance of a

biologically active barrier on the surface of the tailings. This barrier is made up of aerobic and facultative bacteria (bacteria that are capable of living under different conditions) that use dissolved oxygen in the infiltrating water, therefore, maintaining the reducing conditions that are necessary for pyrite to remain bound in mineral form.

MSE and researchers at the Center for Biofilm Engineering at Montana State University (MSU) are investigating the microbial processes involved with establishing and maintaining subsurface and near surface microbial barriers for hydraulic control and microbially catalyzed reactions. Biobarrier technology has been successfully tested in laboratory and meso-scale systems where permeability reductions of up to 5 orders of magnitude were achieved. These experimental systems have proven, likewise, that biobarriers constructed of aerobic or facultative organisms can successfully remove oxygen from infiltrating water to trace levels.

This biological barrier demonstration project is the fourteenth project to be conducted by MSE as part of the MWTP. By conducting this demonstration, the MWTP is illustrating the ability of the microbial biomass to reduce the permeability of mine tailings and remove oxygen from infiltrating water, thus, reducing the generation of AMD. This technology promises to be a cost-effective approach for the stabilization and remediation of acid generating abandoned mine tailings.

### Technology Description

A solution containing bacteria and low-cost nutrients are applied to the top of the tailings pile to form a biological barrier. Following an incubation period, nutrient solution is periodically applied to further develop the biobarrier. The bacteria to be used will be a consortium of aerobic and facultative heterotrophic bacteria originally derived from the mine tailings to be treated. The oxidation of carbon compounds in the nutrient mixture by bacteria in the barrier depletes oxygen in the infiltrating water. Furthermore, bacterial cells and associated extracellular polymers

occupy free pore space within the tailings matrix, greatly reducing permeability. The reduction in water volume flowing through the tailings and depletion of oxygen as water passes through the barrier will mitigate pyrite oxidation and subsequent acid production. The anaerobic conditions and production of organic acids by fermentative bacteria in the biobarrier may also promote the growth of sulfate-reducing bacteria (SRB). The activity of SRB is desirable in that it consumes acid and stabilizes metals by H<sub>2</sub>S-mediated metal sulfide precipitation. Laboratory-scale experiments have demonstrated that biobarriers are capable of generating conditions suitable for SRB growth.

## Status

The mine site selected for implementation of the technology is the Crescent Mine located in the Rimini mining district within the 10-mile creek drainage, approximately 10 miles from the Town of Rimini, MT.

Laboratory testing using samples collected from the Crescent Mine are underway. Field testing is planned to begin in the spring of 1999. Project completion is expected in November 2000.

## ACTIVITY III, PROJECT 15: ENGINEERED TAILINGS CAP DEMONSTRATION

### Project Overview

Processing of metallic ores to extract the valuable minerals from the waste leaves remnant material behind called tailings. In the case of sulfide mineral-bearing ores, process tailings often contain large quantities of sulfide minerals that do not meet the economic criteria for extraction. These remnant sulfide minerals are usually pyrites and nonextracted ore minerals, and the

exposure of these minerals to air and water often leads to the natural production of acidic solutions within the tailings and increased suspended solids in the surface waters during storm events. This technology involves developing an engineered tailings cap that will use a material that can be mixed or slurried in with a large percentage of tailing from the selected tailings site to provide a cap.

## Technology Description

Detrimental environmental conditions as a result of a tailings site include increased sedimentation in surface waters due to runoff events, generation of acid mine drainage, and increased metals loading in surface and groundwaters. This technology would utilize the local tailings, soils and or sands in conjunction with other binder/clay materials to form an impervious cap for the tailings impoundment.

The demonstration consists of two phases: 1) site characterization and materials testing; and 2) cap emplacement and long-term monitoring and evaluation.

Phase One consists of the site characterization studies, including hydrogeological, geological, and geochemical information directly related to the tailings impoundment. The materials testing and development will involve testing, evaluation, and formulation of a capping material for the tailings impoundment.

Phase Two encompasses the application of the selected cap material at the demonstration site and the evaluation of the cap material versus the original tailings material at the site. Long-term evaluation of the capping material will be performed using moisture profiles generated from monitoring equipment.

## Status

Phase one is in the initial stages, the project site selected for this demonstration is the Slaughterhouse Tailings site located west of

the historic mining town of Elkhorn, Montana. Material testing is in progress and will be finalized during the second quarter of 1999. Emplacement of the cap at the selected tailings impoundment is scheduled to be emplaced during the summer of 1999, and the evaluation of the cap will extend through FY 2000.

### **ACTIVITY III, PROJECT 16: INTEGRATED PASSIVE BIOLOGICAL TREATMENT PROCESS DEMONSTRATION**

#### **Project Overview**

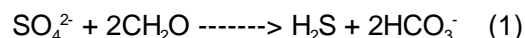
This project, the sixteenth project being conducted by MSE as a part of the MWTP, is demonstrating a protected sulfate-reducing bacteria (SRB) reactor. The objective of this project is to develop technical information on the ability of a protected SRB reactor to passively treat and improve water quality at a remote mine site. A protected SRB reactor system offers advantages over many acid mine drainage (AMD) treatment systems because it does not require a power source or frequent operator attention. For the purposes of this demonstration, the technology will treat the acidic aqueous waste

by removing toxic, dissolved metallic and anionic constituents from the water in situ and increasing the pH so the effluent is near neutral.

#### **Technology Description**

The technology uses a protected SRB reactor to treat AMD by concentrating and immobilizing metals within the reactor and raising the pH of the water. Metal removal processes that can occur in the SRB reactor include adsorption and complexation of metals by organic substrates, biological sulfate reduction followed by precipitation of metals as sulfides, precipitation of ferric and manganese oxides, adsorption of metals by ferric and manganese hydroxides, and filtration of suspended and colloidal materials. However, biological sulfate reduction should be the predominant metal removal mechanism.

Sulfate-reducing bacteria are capable of reducing sulfate to sulfide. Sulfate-reducing bacteria require sulfate (present in AMD) as a nutrient along with an organic carbon source to produce soluble sulfide, acetate, and bicarbonate ions. The soluble sulfide reacts with the metals in the AMD to form insoluble metal sulfides. The bicarbonate ions increase pH and alkalinity of the water (Equations 1 and 2).



The first phase of the project will include field site selection and characterization and laboratory testing. Laboratory testing will be performed to identify design parameters for the field design.

The second phase of the project will include the design and construction of a protected SRB reactor to treat AMD at a selected remote mine site. A protected SRB reactor will likely be constructed within a discharging mine adit or underground near the portal. The reactor, thereby, will be protected from

climatic conditions at the surface, as well as being kept anaerobic. Construction costs can be minimized by emplacing the reactor within the adit or near the portal of the mine eliminating the need for costlier construction deeper within the mine. An organic substrate to nourish the SRB will be selected and used within the reactor. To ensure the appropriate hydraulic conductivity through the reactor, appropriate materials will be added to the organic substrate. At the selected mine site, preferential water flow will already be occurring through the mine adit and discharging through the portal. However, to ensure continued preferential flow through the protected SRB reactor, appropriate materials will be added to the substrate to provide a reactor with a larger hydraulic conductivity than the surrounding geology.

The protected SRB reactor will be designed to accommodate the anaerobic requirements of the microbes and to minimize temperature variations that will occur since the demonstration site will be located at a high elevation in a cold climate.

## **Status**

This project was initiated at the end of FY98. The site selection process has begun.

## **ACTIVITY III, PROJECT 17: LEAD ABATEMENT DEMONSTRATION**

### **Project Overview**

MSE has conducted a technology demonstration in Butte, Montana, that will be of interest to anyone who has lead-based paint in their home. Lead-based paint chips have been shown to be a major factor in childhood lead poisoning. Additionally, traditional methods of paint removal have been shown to damage interior decorative wood moldings and create hazardous wastes.

### **Technology Description**

MSE has demonstrated the ability of a new and innovative technology to remove lead-based paint from interior decorative wood, without destroying the wood. Another critical part of the demonstration is to determine if the new technology will produce paint residues that are nonhazardous. Nonhazardous paint residues can be inexpensively and legally disposed in local landfills, while hazardous wastes must be shipped off for disposal at great expense.

This unique technology is a combined effort of several companies. The key ingredient is LEADX™, which is a dry, granular additive used in the in situ treatment of materials contaminated with lead. LEADX™ is distributed worldwide by Proactive Applied Solutions Corporation (PASCO) of Marietta, Georgia, through an agreement with the products developer, Proactive Environmental Research & Development of Regan, Texas. PASCO worked with Envirobest Corporation (EBC) of San Diego, California, to develop an environmentally responsible paint remover containing the LEADX™ additive. The result is PR40-LEADX™, a water-based liquid chemical that removes the lead paint while simultaneously transforming the lead in the waste stream into a nonhazardous form. The regional distributor for the lead paint abatement technology is Valley Welding and Sandblasting (VWS) of Hamilton, Montana, who was responsible for performing the demonstration in Butte.

Another unique portion of this technology demonstration was removing the LEADX™ products using a granulated dry ice blasting system provided by Cryokinetics of Wichita, Kansas.

Conventional sand blasting may destroy the interior decorative wood and increases the amount of waste that must be disposed. The granulated dry ice, however, vaporizes from a solid form directly to a nonhazardous vapor through a process called sublimation. The harmless carbon dioxide gas disperses in the air while only the lead paint residues fall to the floor. The amount of waste going to disposal is thereby reduced significantly.

MSE enlisted the services of the Butte-Silver Bow County Health Department's Childhood Lead Poisoning Prevention Program (BSB CLPPP) to assist with finding an appropriate residential property for the demonstration and to participate in the demonstration itself. The BSB CLPPP identifies and monitors children with lead poisoning; identifies lead exposures from soil, paint, and dust; and conducts abatement of environmental lead hazards throughout the County. The County also administers a state-wide CLPPP for all children in Montana.

## **Status**

The technology demonstration is scheduled to be completed in February 1999. The final report will be available by mid 1999.

## **ACTIVITY III, PROJECT 18: GAS-FED SULFATE-REDUCING BACTERIA BERKELEY PIT WATER TREATMENT**

### **Project Overview**

Sulfate-reducing bacteria (SRB) are a well-known, effective method for treating acid rock drainage. With the proper conditions of solution temperature and oxidation/reduction potential, and with suitable nutrients available to the SRB, sulfate is electrochemically reduced to sulfide, which forms insoluble precipitates with many metals. In addition, alkalinity is produced that serves to raise the solution pH. Previous and current MWTP projects have successfully demonstrated SRB in remote locations with the goal of providing improved water quality at low cost. Advances have been made in engineered systems utilizing SRB, particularly in the area of providing cheap nutrients to the bacteria, which significantly enhance overall system economics. These advances increase the possibility of utilizing SRB as part of an AMD treatment system in which selected metals are separated and recovered for resale, offsetting overall treatment costs. This project will demonstrate and evaluate a process with the potential to profitably recover copper, zinc, and sodium hydrosulfide from Berkeley Pit water.

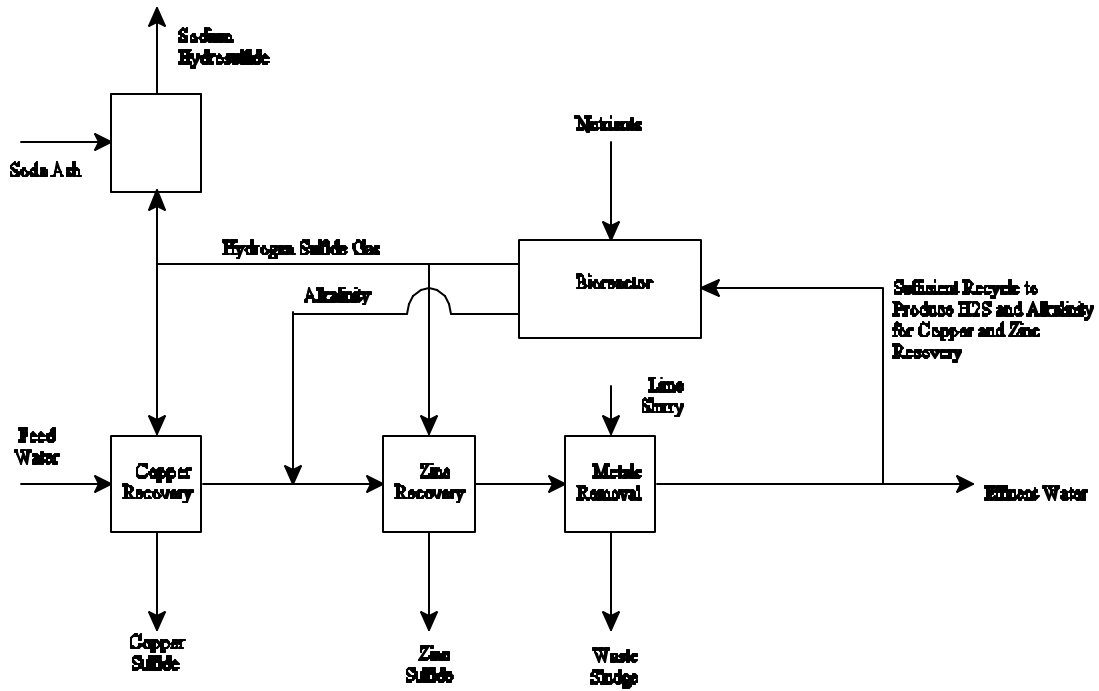
### **Technology Description**

Biomet Mining Corporation of Vancouver, British Columbia, has patented a method utilizing combustion products from natural gas as nutrients for SRB, called the Biosulfide process. This cheap source of nutrients has enabled Biomet to show favorable economics in recovering copper and zinc products from AMD at pilot-scale at several locations in North America. Copper is recovered directly as copper sulfide using hydrogen sulfide gas produced by the SRB; following a pH adjustment using the alkalinity produced by the SRB, hydrogen sulfide gas is used to recover zinc as zinc sulfide. Other products, including sodium hydrosulfide and sulfuric acid, can be produced with downstream processing if the economics at a

specific location are favorable. A generalized schematic of the process is shown in Figure 17.

## **Status**

Initial plans were to conduct bench-scale testing at MSE's facility and to conduct pilot-scale testing near the Berkeley Pit. These plans have changed, and as a result, the pilot-scale testing will be conducted at MSE's facility as well. Bench-scale testing began in October 1998 using a miniplant supplied by Biomet. Initially, the unit will be used to develop biomass for the pilot-scale demonstration. Later efforts with the miniplant will focus on confirming copper and zinc recovery as well as integrating recovery of other metals into the Biomet process. The pilot-scale demonstration is scheduled for the period of February 1999 through June 1999. The final report should be completed by September 1999.



**Figure 17. Biomet Mining Corporations's Biosulfide Process.**

## ACTIVITY IV OVERVIEW

The objective of this activity is to develop, qualify, and screen techniques that show promise for cost-effective remediation of mine waste. The most promising and innovative techniques will undergo bench- or pilot-scale evaluations and applicability studies to provide an important first step to full-scale field demonstrations. Each experiment is assigned as an approved project with specific goals, budget, schedule, and principal team members.

## ACTIVITY IV, PROJECT 1: BERKELEY PIT WATER TREATMENT

### Project Overview

Bench-scale research on treatment of water from the Berkeley Pit is being performed at Montana Tech, in Butte, Montana.

The Berkeley Pit is an abandoned open-pit copper mine in Butte that has been filling with acidic water since pump dewatering of adjacent underground mines ceased in 1982. Flow into the Berkeley Pit has varied from approximately 7.5 million gallons per day (mgd) initially to a current rate of approximately 2.5 mgd.

The water in the Berkeley Pit was chosen for this project due to its accessibility, abundance, and the chemical similarities between it and other acidic mine waters. Studies have been conducted since 1986 on the Berkeley Pit water, and a large amount of analytical data has been previously developed, providing a foundation for this project.

### Technology Description

This project addresses treatability of the acid mine water that is accumulating in the Berkeley Pit. Appropriate treatment techniques were identified and developed. The overall goal was to evaluate technologies that produce clean water, allow for safe waste disposal, and recover selected metals for resale.

Technologies were evaluated by considering their effectiveness, technical feasibility, and potential for technology transfer to similar sites.

Experimental testing consists of four major phases:

**Physical oxidation, neutralization, and metal removal**—this phase consists of using alkaline reagents such as lime, limestone, or soda ash to neutralize the water and cause metals to precipitate as hydroxides. During neutralization, the water is aerated to oxidize iron(II) to iron(III), thereby enhancing sludge settling characteristics and promoting adsorption reactions. Metals removal efficiency and reaction kinetics were studied.

**Metals separation and recovery**—this phase is a two-stage hydroxide precipitation process. Sulfide and hydroxide precipitation were combined for more complete removal of metals. In other tests, metal sulfides were precipitated first to recover metal value, and scrap iron was used to cement copper before neutralization.

**Use of milling waste**—this phase consists of adding tailings slurry (primarily silicates, clay, lime, and limestone) directly to the Berkeley Pit water. This partially neutralized the water and removed some of the heavy metals. This in situ neutralization could potentially reduce reagent consumption and sludge formation for subsequent processing.

**Diversion and treatment of various inflow water sources**—this phase consists of investigating numerous water sources to determine the feasibility of diverting inflow water for treatment. Of the water that flows into the Berkeley Pit, one-third is surface water from the Horseshoe Bend area, and two-thirds is underground water that has penetrated through the mines and surrounding rocks.

## **Status**

All work for this project was completed. The final report has been reviewed and is ready for publication.

## **ACTIVITY IV, PROJECT 2: SLUDGE STABILIZATION**

### **Project Overview**

The Sludge Stabilization Project for mine waste was a bench-scale research project conducted at Montana Tech.

The purpose of this research project was to study the properties and stability of sludges generated by remediation of acid mine waters. Results of the study were used to determine the best methods for sludge handling and disposal. One source of acid mine water being studied was from the Crystal Mine, which is located approximately 7 miles north of Basin, Montana. The other source was the water from the Berkeley Pit in Butte, Montana. Besides being acidic, these waters contain toxic concentrations of iron, manganese, copper, zinc, arsenic, and sulfate, which is typical of many hard rock mining operations throughout the Western United States.

Past research on remediating acid mine water has focused primarily on water treatment techniques, and little emphasis has been placed on the stability of the sludge that is generated. To address this issue, faculty at Montana Tech, with expertise in chemistry, geochemistry, metallurgy, and environmental engineering, formed a research team to study the properties and stability of this sludge.

### **Technology Description**

The three types of sludge studied were: base-initiated sludge, inorganic sulfide-initiated sludge, and sulfate-reducing bacteria-initiated sludge. Appropriate solid-liquid separation techniques were used to isolate the solid phases for chemical characterization and stability tests.

Chemical characterization studies included quantifying the various element-solid associations, i.e., adsorbed, surface-precipitated, and coprecipitated contaminants. These studies then identified and quantified the divalent and trivalent forms of iron and the trivalent, pentavalent, and methylated forms of arsenic. Once analytical techniques were verified for each of the sludges, they were applied to as-generated sludge and aged sludge.

Based on the chemical properties of these sludges, various storage environments were proposed and evaluated. The sludge stability research included standard regulatory tests and specifically designed tests, e.g., biostability tests, based on the selected specific disposal options, including storage in the natural environment. The results of these tests were translated into stability-enhancement studies, including the effect of aging the sludge in a temporary storage environment and treating the sludge with chemical additives before final storage.

The results of this sludge characterization and stability study identified characterization techniques and stability procedures that have application to sludges generated through other water-treatment procedures.

## **Status**

All work for this project was completed. The final report was written and is being reviewed.

## **ACTIVITY IV, PROJECT 3: PHOTOASSISTED ELECTRON TRANSFER REACTIONS RESEARCH**

### **Project Overview**

Research efforts under the MWTP for the remediation of mine wastewaters have focused primarily on removing toxic heavy metal cations from solution. However, little attention has been given to toxic anions that can be associated with the heavy metal cations. Conventional treatment technologies generally require chemical process streams that generate sludge by-products. Consequently, researchers at Montana Tech are attempting to identify and enhance naturally occurring processes that would help remediate toxic anions while minimizing treatment by-products. In this regard, the use of dissolved and solid photocatalysts is being investigated for the removal of cyanide and nitrate anions from mine wastewaters.

### **Technology Description**

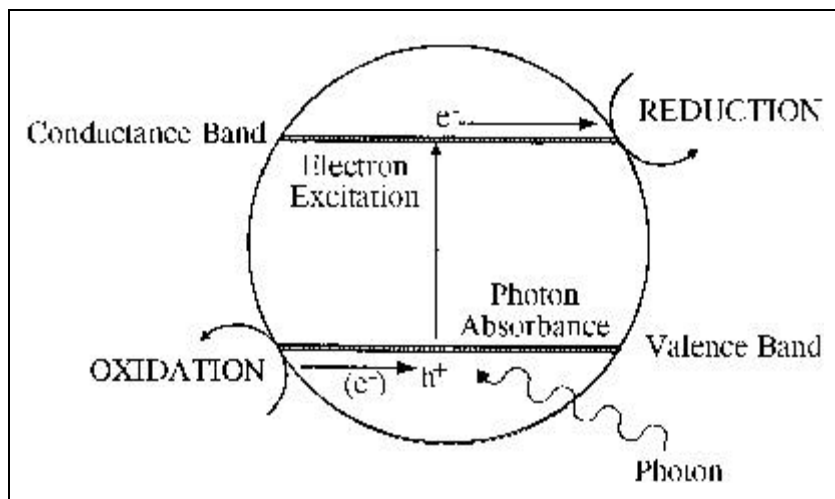
On absorption of electromagnetic radiation (predominantly UV or visible light), photocatalysts enter an excited state where electrons are promoted from a valence band into a conduction band (see Figure 18). Electrons in conduction bands can then be donated to species, causing that species to undergo reduction. Simultaneously, the absence of electrons in the valence band can cause other species to donate electrons to the valence band and thereby undergo oxidation. These electron-transfer reactions can cause the species to decompose. However, decomposition can only occur if the electrochemistry of the system is well defined, e.g., oxidation-reduction potential, pH, concentration, and temperature, and if the proper intensity and frequency of electromagnetic radiation is available. This radiation may be natural sunlight but inevitably must be artificial to accommodate seasonal, daily, and hourly changes due to winter, nightfall, and cloudiness.

Solid photocatalysis is a proven technology while dissolved photocatalysis is relatively new.

With solid photocatalysis, reactions only occur if the species are adsorbed at the surface of the solid photocatalyst. The overall rate of the photocatalytic reactions are, thus, dependent on the concentration of the species, the rate of adsorption of the species, the available surface area of the photocatalyst, and the rate of desorption of the decomposition products. With dissolved photocatalysts, reactions occur in bulk solution and are only dependent on concentration. Consequently, reaction kinetics with dissolved photocatalysts can be at least three orders of magnitude faster than with solid photocatalysts.

### **Status**

All work for this project was completed. The final report was revised and published.



**Figure 18. Schematic illustrating the basic process of photoassisted electron transfer reactions.**

## **ACTIVITY IV, PROJECT 3A: PHOTOASSISTED ELECTRON TRANSFER REACTIONS FOR METAL-COMPLEXED CYANIDE**

### **Project Overview**

Previous research efforts under the MWTP for the remediation of mine wastewaters predominantly focused on removing toxic heavy metal cations from solution. This was accomplished with chemical processes that generated heavy-metal sludges that were then removed from the water stream by solid-liquid separation processes. However, many of the anions associated with the heavy metal cations in the wastewater are also toxic but remain in solution even after the sludge is generated and separated. Consequently, researchers at Montana Tech are examining processes to remediate the anions, particularly sulfur as sulfate, arsenic as arsenite and arsenate, nitrate, cyanide and metal-complexed cyanides. In this project, the remediation of metal-complexed cyanide is being investigated using several photolytic methods with the intent to identify and enhance naturally occurring remediation processes.

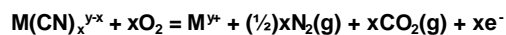
Overwhelming evidence shows that natural processes occur to heal environmental scars caused by mining activities. These processes

include electron-transfer reactions that lower the concentrations of the anionic mobile toxic constituents in surface and groundwaters through interactions with electromagnetic radiation (predominantly UV radiation but some visible light) from the sun. However, such direct natural photolytic processes suffer at night, on cloudy days, and in winter months. During these periods, artificial radiation sources are needed for sustainment. Furthermore, because the photolytic processes usually proceed slowly, catalysts are used to absorb the radiation and transfer the energy to the reactants to remediate the water within more acceptable time frames. Such photocatalysts are either solid semiconductors (heterogeneous photocatalysts) or dissolved radicals in solution (homogeneous photosensitizers).

### **Technology Description**

**Background**—When electromagnetic radiation is absorbed, electrons in the absorbing species pass from a singlet ground state ( $S_0$ ) to an excited electronic state ( $S_1$ ) as shown in Figure 18. As long as the electron remains in the excited state, the absorbing species are more susceptible to their chemical environment and are, therefore, more apt to participate in electron-transfer reactions. The absorbing species undergo photoreduction when it donates the excited electron.

Conversely, photooxidation occurs when the absorbing species accept an electron. In either case, the photoreduction and photooxidation reactions can lead to the destruction of the mobile toxic constituent. For metal-complexed cyanide, only photooxidation can be used and in a reaction similar to cyanide photooxidation (see Project 3) where carbon dioxide and nitrogen gases are reaction products:



Clearly, solutions containing metal-complexed cyanides can also be rendered nontoxic through photolysis.

However, it is important to note that several competing processes may occur (see Figure 18) and must be prevented and/or minimized to maximize the efficiency of photoassisted electron transfer reactions. Furthermore, the photooxidation reaction becomes more difficult depending on the strength of the M-CN bonds. For this reason, the metal-complexed cyanides have been grouped as weak acid dissociables and strong acid dissociables. In this regard, certain metal-complexed cyanides should be easy to photolytically remediate (copper and zinc) while others should be much more difficult (cobalt and gold).

**Direct Photolysis**—In this process, the mobile toxic constituent being remediated must absorb the electromagnetic radiation. Although this phenomenon is rare, it does occur with some metal-complexed cyanides but is dependent on the solution conditions. Research was conducted to identify these conditions.

**Homogeneous Photolysis**—In this process, aqueous photosensitizers absorb the

electromagnetic radiation and then transfer the photon energy to the mobile toxic constituents being remediated. Because the process occurs in bulk solution, its kinetics are dependent on the solution conditions and the concentrations of the photosensitizers and the mobile toxic constituents. When the aqueous photosensitizer is not consumed during the process, it is referred to as homogeneous photocatalysis. In this regard, research is being conducted to identify the conditions needed for using either homogeneous photosensitizers or homogeneous photocatalysts for metal-complexed cyanide remediation.

**Heterogeneous Photocatalysis**—In this process, solid semiconductors are used to absorb the electromagnetic radiation and then transfer the photon energy to the mobile toxic constituent being remediated. However, electron transfer reactions can only occur if the mobile toxic constituent is adsorbed at the surface of the semiconductor. Thus, reaction kinetics are dependent on the mobile toxic constituent concentration as well as the rate of adsorption of the constituent, the available surface area of the semiconductor, and the rate of desorption of the reaction products. Consequently, reaction kinetics can be three orders of magnitude slower than reactions with homogeneous photolysis.

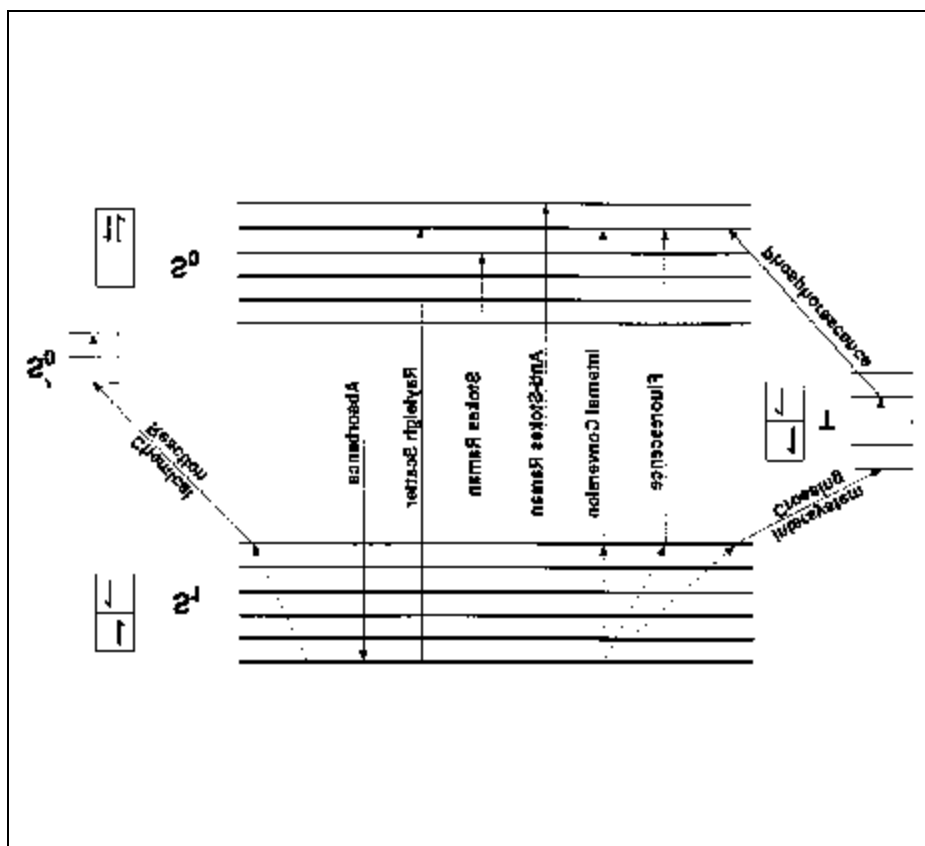
Nevertheless, reaction efficiencies are usually higher with heterogeneous photocatalysis due to the higher efficiency of photon capture and the increased "life" of the electron in the excited state. This is ultimately attributed to the properties of the semiconductor. With semiconductors, electrons are promoted from the valence band and into the conductance band across a band gap (Figure 19). The photon energy must be greater than or equal to the band gap energy. Excited electrons in the conductance band can then be donated to the mobile toxic constituent to induce its reduction. Likewise, the electron vacancy or "hole" in the valence band can accept electrons from the mobile toxic constituent and thereby induce its oxidation. The process is similar to the process described earlier (see Figure 18); however, it is evident that solution conditions must also be well-defined to control reactant adsorption and product desorption.

In this regard, studies are being conducted to optimize these conditions for metal-complexed cyanide oxidation reactions. For now, only anatase ( $\text{TiO}_2$ ) is being investigated because it has the highest known efficiency of semiconductors.

## Status

This project is a continuation of the nitrate and cyanide project (Project 3) but with the inclusion of photolytic research on metal-complexed cyanides.

The final report was published.



**Figure 19.** Semiconductor electrons promoted from the valence band, into the conduction band, and across a band gap.

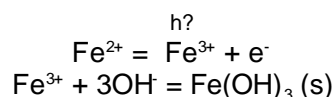
## ACTIVITY IV, PROJECT 3B: PHOTOASSISTED ELECTRON TRANSFER REACTIONS FOR BERKELEY PIT WATER

### Project Overview

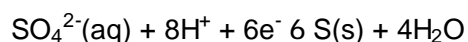
See Activity IV, Project 3A for Project Overview.

### Technology Description

**Background**—When electromagnetic radiation is absorbed, electrons in the absorbing species pass from a singlet ground state ( $S_0$ ) to an excited electronic state ( $S_1$ ) as shown in Figure 18. As long as the electron remains in the excited state, the absorbing species are more susceptible to their chemical environment and are, therefore, more apt to participate in electron-transfer reactions. The absorbing species undergo photoreduction when it donates the excited electron. Conversely, photooxidation occurs when the absorbing species accept an electron. In either case, the photoreduction and photooxidation reactions can lead to the precipitation of mobile toxic constituents. For example, ferrous cations can be precipitated as ferri-hydroxide after being photooxidized to ferric cations:



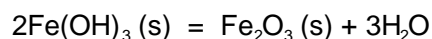
This reaction mechanism may account for the natural precipitation events observed in Berkeley Pit water. Once the iron is precipitated and separated, photolysis and/or conventional hydrometallurgical processes can then be used to recover the valuable mobile toxic constituents. On the other hand, a photoreduction reaction is exemplified by sulfate conversion to elemental sulfur:



Clearly, acid mine waters can be remediated through photolysis. However, it is important to note that several competing processes may occur (see Figure 18) and must be prevented

and/or minimized to maximize the efficiency of photoassisted electron transfer reactions.

Nevertheless, reaction efficiencies are usually higher with heterogeneous photocatalysis due to the higher efficiency of photon capture and the increased "life" of the electron in the excited state. This is ultimately attributed to the properties of the semiconductor. With semiconductors, electrons are promoted from the valence band and into the conductance band across a band gap (see Figure 19). The photon energy must be greater than or equal to the band gap energy. Excited electrons in the conductance band can then be donated to the mobile toxic constituent to induce its reduction. Likewise, the electron vacancy or "hole" in the valence band can accept electrons from the mobile toxic constituent and thereby induce its oxidation. The process is similar to the process described earlier (see Figure 18); however, it is evident that solution conditions must be well-defined to control reactant adsorption and product desorption. In this regard, studies are being conducted to optimize these conditions for metal-complexed cyanide oxidation reactions. For now, both hematite ( $\text{Fe}_2\text{O}_3$ ) and anatase ( $\text{TiO}_2$ ) are being investigated. Hematite is important because it can actually be formed by recycling the precipitated ferrihydrite



whereas the anatase is important because it has the highest known efficiency of semiconductors.

### Status

The final report was published.

## ACTIVITY IV, PROJECT 4: METAL ION REMOVAL FROM ACID MINE WASTEWATERS BY NEUTRAL CHELATING POLYMERS

### Project Overview

A bench-scale research project is in progress at Montana Tech to eliminate or minimize

some current economic or technical difficulties that exist in treatment technologies for acid mine wastewater. The novel technology is based on neutral chelating polymers that can have their chelating property turned on and off. The chelate switch will be based on known electrochemical or photochemical properties of electrically conducting polymers.

## Technology Description

Chelates are chemical substances that have more than one binding site on the molecule; these added binding sites attach a molecule to a metal ion more strongly than a single binding site. The result is that chelates can be very effective at removing metal ions from wastewater. Chelates can be ionic or neutral. Ionic chelates exchange a cation ( $H^+$  or  $Na^+$ ) for the metal ion removed from the solution. Neutral chelates are electrically neutral and do not add material to the solutions when the metal ions are removed.

The removal of metal ions from aqueous solutions is presently accomplished by a variety of chemical and electrochemical processes. These techniques have distinct advantages in the appropriate situations (pH range, concentration range, matrix composition, etc.); however, they may not be practical under less-than-optimum operating conditions.

The goal of this project is to develop an alternate technology that requires no additional chemicals and that can produce

a marketable product, such as pure metals, and reduce costs and waste volume. The research project is a collaborative effort between academic and government resources, including the Haskell Indian Nations Universities' Haskell Environmental Research Studies Center. Initially, the project focus was on the design of chelating polymer systems for laboratory study and for theoretical study (molecular modeling). The first polymer systems were based on current literature information. Modeling results were compared to experimental and literature results as a means to test the validity of the theoretical data.

The validated modeling procedure was used to design and test a variety of neutral chelating systems for their capability to remove metal ions and associated anions from acid mine wastewater. The neutral chelating polymers determined to be most effective for water cleanup by the preliminary experimentation and the modeling studies were studied more thoroughly. The polymeric systems were evaluated for their removal efficiencies, contaminant capacity, ruggedness, ease of use, and cost effectiveness. Other important parameters identified in the preliminary studies were also used in the systems evaluations.

A more detailed process evaluation procedure was developed from the results of the refined experimentation. The selected polymeric system was then completely studied using a variety of synthetic and actual mine wastewater.

## Status

All work for this project was completed. The final report was published.

## ACTIVITY IV, PROJECT 5: REMOVAL OF ARSENIC AS STORABLE STABLE PRECIPITATES

### Project Overview

The objective of this project is to strip arsenic from solutions in such a way as to produce apatite mineral-like precipitated products that are stable for long-term storage in tailing pond environments. Substitution of arsenic into an apatite structure will provide a solid solution

mineral compound that is environmentally stable for outdoor pond storage.

## Technology Description

Earlier research demonstrated that a precipitation technique is effective in removing arsenic (to low micrograms/liter concentrations) from aqueous solutions (EPA-supported project). The precipitation is conducted in a way to form a solid solution compound containing arsenate and phosphate in an apatite mineral-like phase. This solid is stable to the EPA's Toxicity Characteristic Leaching Procedure (TCLP), and more importantly, the solubility is one to two orders of magnitude less than calcium arsenate in aqueous solutions over the pH range of 9 to 12 (the range of pH values maintained in tailing ponds).

In the early 1980s, it was demonstrated that lime precipitation of calcium arsenate with subsequent storage in a tailings pond environment is unacceptable because at pH levels above approximately 8.5, calcium arsenate will be converted to calcium carbonate (by carbon dioxide in air) with the release of arsenic into the aqueous phase. Removal of arsenic by precipitation as calcium arsenate has been discontinued by industry and has been replaced by ferric arsenate precipitation (EPA's Best Demonstrated Available Technology for arsenic-bearing solutions). However, even though low concentrations of arsenic in solutions can be achieved by ferric precipitation, it has been demonstrated that the removal from solution is actually an adsorption phenomena. Therefore, long-term stability of such residues in tailings pond environments may not be appropriate, hence the need for the present study.

### Stability of Mineral-Like

**Residues**—Montana Tech researcher's approach to arsenic storage was to form a mineral-like phase that shows equilibrium-phase stability under tailings pond environmental conditions. If equilibrium-phase stability is achieved (for a given environment), then long-term stability would be ensured (at least for as long as the environmental

conditions are maintained). This project is supporting an intensive investigation of the formation of arsenic precipitates in two systems, i.e., the calcium-arsenic-phosphate (apatite-like solid solutions of arsenate and phosphate) system, and the ferric-arsenic-phosphate (phosphoscorodite-like solid solutions of arsenate and phosphate) system. Both of these systems show great promise for industrial application, if long-term stability can be demonstrated.

## Status

The initial phase was completed. The first portion of long-term stability tests were performed, and data from these tests is being evaluated. The project was completed in May 1997; however, an extension of the project to complete the second portion of the long-term stability tests was granted in the spring of 1997.

The precipitation "recipe" was applied to two industrially contaminated waters, and the long-term stability of the resulting products will be tested. Successful demonstrations will result in a new way to treat arsenic-bearing wastewaters and mine drainage solutions.

## **ACTIVITY IV, PROJECT 7: BERKELEY PIT INNOVATIVE TECHNOLOGIES PROJECT**

### **Project Overview**

The purpose of the Berkeley Pit Innovative Technologies Project is to provide a test bed for high risk/innovative technologies for the remediation of Berkeley Pit water. The project is focused on bench-scale testing of remediation technologies to help assist in defining alternative remediation strategies for the EPA's future cleanup objectives for Berkeley Pit waters.

The project will focus on bench-scale testing of innovative technologies for treating the water flowing into and existing in the Berkeley Pit. Individuals, companies, or academic institutions with existing remediation technologies are invited to demonstrate their process for the project and write a report summarizing their process including the results of their bench-scale test. A copy of the report from each test will be forwarded for evaluation by the EPA Region VIII field office, the EPA NRMRL, and the DOE Resource Recovery Project, also implemented by MSE.

The project seeks subcontractors to perform bench-scale tests of innovative remediation technologies for water flowing into or existing in the Berkeley Pit. Ideally, the subcontractor's process will treat Berkeley Pit water to produce water of sufficient quality that it can be discharged with no further treatment and produce a small quantity of relatively stable residue containing highly concentrated amounts of the elements and compounds found in the Berkeley Pit.

### **Avenue for Participation**

#### **Option 1: Funded Testing at Montana Tech**

Montana Tech will provide water from the Berkeley Pit and will store and dispense

water from the bench-scale tests. Montana Tech has also provided a laboratory to be used for the remediation testing.

Quality control during the demonstration tests is essential. Before beginning bench-scale tests at Montana Tech, a quality assurance project plan must be developed in sufficient detail to demonstrate that the intended measurements are appropriate for achieving project objectives, quality control procedures are sufficient for obtaining data of known and adequate quality, and such data will be defensible if challenged technically.

Upon completion of bench-scale tests and before leaving Montana Tech, the subcontractor will be required to write an exit report with supporting data tables, summarizing the process and results of the bench-scale tests.

#### **Option 2: Funded Testing Off Site**

Montana Tech will facilitate delivery of Berkeley Pit water to the subcontractor's site. Quality control during the demonstration tests is essential, and the quality assurance project plan must be submitted and approved before any water will be shipped. The subcontractor must also satisfy project personnel that proper hazardous waste and safety programs are in place at their site.

Upon completion of off-site bench-scale tests, the subcontractor will be required to write and submit a final report with supporting data tables, summarizing the process and results of the bench-scale tests.

#### **Option 3: Unfunded Alternative Avenues for Participation**

*Participation at Montana Tech*—There may be potential researchers who are willing to bring their technology to the project laboratory under their own financial support. The Project Manager for the Berkeley Pit Innovative Technologies Project and the Project Manager for MWTP Activities from Montana Tech will review each technology that may be presented under this avenue on a case-by-case basis for testing at any time. Potential unfunded participants are encouraged to

contact the project managers to initiate discussion before submitting a proposal.

*Off-Site Participation*—The Berkeley Pit Innovative Technologies Project has a mechanism in place to ship water to credible researchers. Berkeley Pit water will be on hand for shipping from the project laboratory to facilitate the work of other researchers. The requirements for the project to ship water are that the investigators:

- can demonstrate their work will contribute to the investigation of solutions to the remediation of Berkeley Pit waters;
- will return a timely report to the project on the results of their research;
- can demonstrate they have satisfactory hazardous materials handling and disposal capabilities; and
- have an adequate safety plan.

## **Status**

- Phase I—Three funded and two unfunded demonstrations were completed. All final reports were reviewed and published.
- Phase II—Three funded demonstrations were completed. The final reports were written and are being reviewed.
- Phase III—Three funded demonstrations are underway. The final reports are being written.

## **ACTIVITY IV, PROJECT 8: PIT LAKE SYSTEM—CHARACTER-IZATION AND REMEDIATION FOR THE BERKELEY PIT**

### **Project Overview**

An interdisciplinary team of Montana Tech researchers (funded by the MWTP), is currently studying several aspects of the Berkeley Pit Lake system to better understand the system as a whole, which may lead to new or improved remediation technologies to be used during future cleanup. The information obtained from the studies will be used to predict future qualities of the water, to evaluate the natural rate of remediation, to determine if partial in situ remediation may be practical prior to expensive pump and treat remediation, and to predict water quality for similar bodies of water in the United States. The following research is being conducted on the Berkeley Pit Lake: Biological Survey of Berkeley Pit Water; Sediment/Pore Water Characterization; Sulfate-Reducing Bacteria; Surface Oxidation Reactions; Organic Carbon; and Sedimentation Rates.

### **SRB Activity in Berkeley Pit Lake Sediments and Potential for In Situ Bioremediation**

Research is being conducted to determine if there is sulfate-reducing bacteria (SRB) activity in the sediments of the Berkeley Pit Lake and how these organisms could be utilized for an in situ bioremediation process. SRB reduce sulfate to sulfide, which then may react with dissolved metals to form highly insoluble metal sulfides. Bicarbonate, which has the potential to reduce the acidity of the water, is also a product of sulfate reduction. Enhancing rates of sulfate reduction in the sediments may provide an effective mechanism for remediating the water in the Berkeley Pit. The key to starting in situ bioremediation of the Berkeley Pit Lake could be to activate the SRB present in the sediment by offering suitable nutrient sources. To date, SRB have been isolated from water samples collected during November 1997. The sediment samples for this project will be collected during the spring and summer of 1998.

### **Characterization of Surface Berkeley Pit Water**

Research is being conducted on the natural phenomena occurring near the surface of the Berkeley Pit Lake. Results and data collected

will not only provide a basic understanding of the quality of the water in the Berkeley Pit but will also predict how fast the water can renew itself to ensure a constant supply of water for future treatment. Ultimately, this research will show how naturally occurring processes can be enhanced and developed into a remediation strategy. The results obtained from this research will not be limited to the Berkeley Pit water; they will also apply similar pits and ponds created by metal mines throughout the Western United States. To date, a large column has been constructed to study the effects of ultraviolet light on the water.

### **Investigation into the Types and Amount of Organic Substances in the Berkeley Pit Water**

Research is being conducted to determine the amounts and types of organic compounds in the Berkeley Pit water. There are several potential sources for organic carbon in the Berkeley Pit water, including decay products from in situ biological life forms, hydrocarbon fuels and lubricants, and humic substances naturally present in the influent waters to the Pit. The source and concentration of the organic carbon will determine the effects the carbon has on the pit lake chemistry and any beneficial or detrimental effects on various remediation technologies. To date, several samples have been analyzed for total organic carbon.

### **Determination of Sedimentation Rates**

Experimental work is being conducted to determine the sedimentation rate and the properties of the sediment with respect to depth in the Berkeley Pit water column. The sediment properties will be the identity of the crystalline and/or amorphous solid phases and the concentrations of the minor and trace elements in each different solid phase. The results obtained from this research would provide guidance as to what type of treatment technology would be the most beneficial; in situ or ex situ. To date, a vertical profile has

been analyzed at three different points in the Berkeley Pit to a depth of 300 feet.

### **Sampling Berkeley Pit Lake**

The Montana Bureau of Mining and Geology (MBMG) is responsible for collecting samples from the Berkeley Pit. Several MBMG personnel will collect a variety of samples over several separate sampling events. Samples will include water from depths of 0.5, 1, 2, 5, 10, 25, 50, 100, 200, and 300 feet in three to four different locations. At one of the above locations, samples will be collected at 100-foot increments from the 300-foot depth to the bottom, approximately 900 feet. Also, sediment cores samples will be taken at the 200-foot level and at the deepest point in the Pit.

Each of these pit lake research projects will be managed independently with a deliverable required for each project. The project managers will see that all projects are synthesized, and that information flows swiftly between researchers. Monthly pit lake research seminars will be held with each team member presenting their latest results.

Although the Berkeley Pit Lake system is the test bed, other waters will be experimented with when possible. The focus of the research will remain fluid enough to apply the remediation strategies determined here to other pit lake systems.

### **Status**

The project was completed in December 1998, and the final report is being reviewed.

## **ACTIVITY IV, PROJECT 9: PIT LAKE SYSTEM—DEEP WATER SEDIMENT/PORE WATER CHARACTERIZATION AND INTERACTIONS**

### **Project Overview**

This project involves collecting samples and data to identify the sediment/pore water

resident conditions, solution phase speciation, and solid phase chemical, physical, and mineralogical characteristics that presently exist within the upper layer and deeper layers of the sediment/pore water deep-water deposits.

The project was completed in December 1998, and the final report is being reviewed.

The thesis to be proven (or disproven) by this investigation is that conditions are formed in the sediment system that allows for the formation of metal sulfides, i.e., reducing/pH conditions that support the formation of metal sulfides. If sulfide presence in the sediment layer is shown, then the conditions will be favorable for long-term environmentally safe storage of metal-bearing compounds. Also, if strong reducing conditions exist in the sediment layer, then pore water is anticipated to be relatively clean (compared to upper layer water). Therefore, assuming our thesis is proven, several remediation techniques can be envisioned, e.g., metal sulfides could be formed from dissolved metals in the upper water system (which settle to the sediment deposit) by sulfide addition (or by sulfate-reducing bacteria) or a portion of the pit water could be treated externally by sulfide addition (or by sulfate-reducing bacteria) and the resulting sludge pumped into the sediment layer for safe storage; or relatively clean water could be pumped from the sediment region that would require only a polishing type final clean up before release.

The specific tasks to be undertaken during this study includes:

- Collecting deep water upper layer sediment samples.
- Collecting subsurface sediment/pore water samples.
- Characterizing and speciation of sediment solids and subsurface pore water.
- Modeling the system to understand the controlling sediment formation mechanism (this includes sediment formation experimentation).

## **Status**

## ACTIVITY IV, PROJECT 10: PIT LAKE SYSTEM—BIOLOGICAL SURVEY OF BERKELEY PIT WATER

### Project Overview

Very little is known about the organisms that are found in Montana's waters impacted by acid mine waste. One of the few references to algae is simply a checklist without illustrations (Prescott and Dillard, 1979); however, little mention is made of mine areas.

The only other person who has studied the algae (mostly diatoms) of Montana is Loren Bahls (1984), but much of his work is unpublished (personal communication).

Even less is known about the diversity of protists, fungi, and bacteria that inhabit these sites. Consequently, this area of research is quite intriguing because numerous organisms are clearly growing in water as low as pH 2 loaded with high accumulations of metals. What is most significant is that these extremophiles may be potential organisms to bioremediate contaminated sites.

The Berkeley Pit Lake system is one of the largest contaminated sites in North America and is part of the largest superfund site in the United States. The Pit is 542 m deep with a lateral extent of approximately 1.8 km by 1.4 km across the rim. The only larger pit mine in the United States is the Bingham Pit in Salt Lake City, Utah (Davis 1989). The chief difference between the two pits is that the Berkeley Pit has approximately 266 m of water in it that is rising at a rate of about 8 m/year. Consequently, this represents roughly 1,140 billion liters of pH 2.7, metal laden, contaminated water and has been designated a Superfund project for clean-up. This emphasizes how important this research may be to the State of Montana and to the United States, but there are even more contaminated, larger sites throughout the world. It is the goal of this research to begin to gain an understanding of the microbial ecology of the Berkeley Pit Lake system, which will ultimately provide necessary data for bioremediation studies and may apply to other contaminated locales worldwide.

The primary goals of this study are both to determine species diversity and numbers for organisms present in these mine waste areas and to determine their potential ecological role in the system for bioremediation.

Various beneficial processes occur because of algal and photosynthetic bacterial growth in aquatic habitats. These processes are important because they may affect the chemistry in a number of ways.

- These organisms are primary producers and, as a result of their physiology, naturally produce bicarbonate to raise the pH of acidic solutions in which they are growing.
- As algae grow, they leak excess photosynthates that, in turn, promote bacterial growth.
- These microbes play a role in the biological magnification of toxic materials (each trophic level of the food web will increase the concentration of many metals ten times).
- Photoautotrophs oxygenate the water that will promote aerobic activity.
- Photoautotrophs are important in biogeochemical cycling of carbon, nitrogen, phosphorus, sulfur, and other elements—most importantly nitrogen fixation and sulfate reduction.
- Algal cells may directly sorb metal ions through several mechanisms that include ion exchange, complexation, and physisorption.
- Accumulation and eventual decomposition of algal biomass will increase the organic carbon component of the mine waste systems which, in turn, will promote heterotrophic growth of bacteria, fungi, and protozoans.
- Algal biotransformation or enzyme-catalyzed conversion of metals will result in less toxic organic compounds.

### Status

The project was completed in December 1998, and the final report is being reviewed.

## **TECHNOLOGY TRANSFER ACTIVITY V OVERVIEW**

This activity consists of making technical information developed during MWTP activities available to industry, academia, and Government agencies. Tasks include preparing and distributing MWTP reports, presenting information about the MWTP to various groups, holding Interagency Agreement Management Committee meetings, sponsoring mine waste conferences, and working to commercialize treatment technologies.

### **Fiscal Year Highlights**

- The MWTP Annual Report was published. This report explains the MWTP and summarizes accomplishments for FY96. A similar report will be published each year.
- Several MWTP professionals appeared at varied meetings to discuss the Program with interested parties. Many mine waste conferences, as well as mining industry meetings, were attended.
- Investigations were conducted on how best to integrate and interface with the ongoing technology transfer activities of the Federal Government.

## **TRAINING AND EDUCATION ACTIVITY VI OVERVIEW**

Through its education and training programs, the MWTP continues to educate professionals and the general public about the latest information regarding mine and mineral waste cleanup methods and research. This effort is being directed by the Professor of Mining Engineering at Montana Tech.

As a result of rapid technology and regulatory changes, professionals working in the mine- and mineral-waste areas often encounter difficulties in upgrading their knowledge and skills in these fields. In recent years the environmental issues related to the mining and mineral industries have received widespread public, industry, and political attention. While knowledge of current research and technology is vital for dealing with mine and mineral wastes, time and costs may prevent companies from sending employees back to the college classroom.

Through short courses, workshops, conferences, and video outreach, Activity VI of the MWTP educates professionals and the general public and brings the specific information being generated by bench-scale research and pilot-scale technologies to those who work in mine- and mineral-waste remediation.

### **Fiscal Year 1998 Highlights**

- The *Mine Design, Operations, and Closure Conference '98* conducted in April 1998, continued last year's interagency cooperation. The 5-day event was cosponsored by the U.S. Forest Service; U.S. Bureau of Land Management; Montana Department of State Lands; MSE; Haskell Environmental Research Studies Center; several other private companies; and Montana Tech. During the conference, experts presented overviews on such topics as predictive chemical modeling for acid mine drainage, mine water quality source control, state-of-the-art containment technologies, and innovative pit reclamation. Over 150 mine operators, consultants, and professionals from the private and public sectors attended the conference.
- The Mine and Mineral Waste Emphasis Program now has an enrollment of 13 students, with all of them receiving funding from the MWTP. This is an interdisciplinary graduate program that allows students to major in their choice of a wide variety of technical disciplines while

maintaining an emphasis in mining and mineral waste.

- A group of Mine and Mineral Waste Emphasis graduate students attended the Mine Design, Operations, and Closure Conference '98.
- A cooperative agreement is in place for work with the Haskell Environmental Research Studies Center at Haskell Indian Nations University.
- Graduate students in the Mine and Mineral Waste Emphasis Program are working on projects in Activities III and IV.
- The Mine and Mineral Waste Emphasis Program continued to offer the courses, *MWTP Field Demonstrations* and *MWTP Bench-Scale Research*. These courses acquainted the Mine and Mineral Waste Emphasis Program students to the other activities of the MWTP.

## Future Activities

The following training and education activities are scheduled for the first part of 1999:

- The MWTP Training and Educational activities will offer the Mine Design, Operations, and Closure Conference '99 in April 1999.
- The MWTP is working on a cooperative education package for the Montana Department of Environmental Quality.
- All funded Mine and Mineral Waste Emphasis Program graduate students will work on mine waste-oriented projects as a part of their funding requirements.

## FINANCIAL SUMMARY

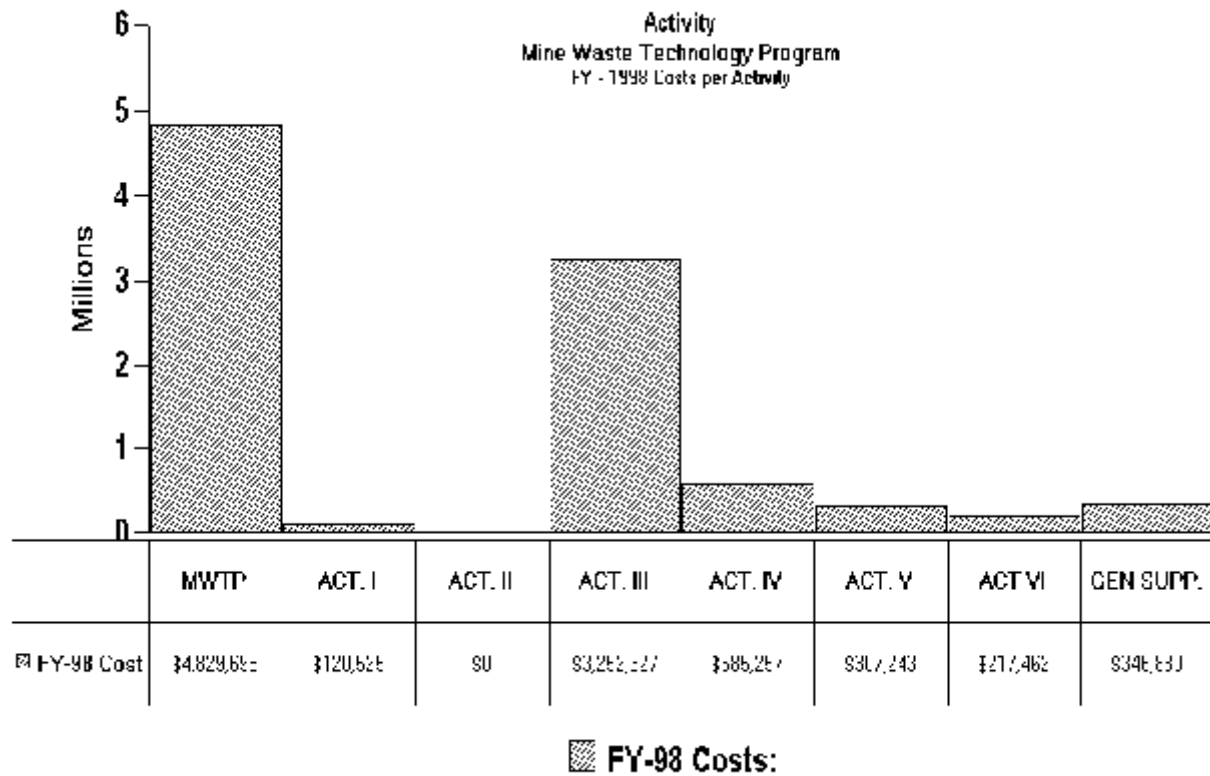
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Total expenditures during the period October 1, 1997, through September 30, 1998, were \$4,829,695, including both labor and non-

labor expense categories. All costs incurred after September 30, 1998, will be included in the Fiscal 1999 Annual Report.

The cumulative authorized budget for the period was \$5,725,000.

Individual activity accounts are depicted on the performance graph (Figure 20).



**Figure 20. Mine Waste Technology Program FY98 performance graph, costs per activity.**

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